PHYSIOLOGICAL DATA ACQUISITION SYSTEM AND MOTION SICKNESS PREVENTION TRAINER

THESIS

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Capt USAF

Charles N. Peterson
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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

Orville A. Earl, B.S. Capt USAF
Charles N. Peterson, B.S. Capt USAF
Graduate Electrical Engineering

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Preface

The goal of this thesis project is to provide an extremely powerful tool for studying the effects and possible cures for motion sickness. We are deeply indebted to the many people who have helped us to reach this goal. We apologize if we fail to mention anyone who helped; this would be purely an oversight on our part.

We appreciate the immeasurable help which we received from our thesis committee members: Maj. Larry Kizer, Dr. Matthew Kabrisky, Dr. Lynn Wolaver, and LtCol Charles Hatsell. A special thanks to Maj. Kizer for the advise and patience he provided as our thesis advisor.

We would like to thank Dr. William Toscano and Dr. Patricia Cowings of Nasa-Ames Research Center. It is unlikely that we could have succeeded if they had not freely shared their wealth of knowledge and experience with us.

We are very grateful to the fine people in the AFIT shop, especially Dave, who spent many hours helping us to develop our ideas and turning them into reality. Many thanks to the fine people in the AFIT Electrical Engineering Lab for your tireless help.

To our wonderful children and lovely wives, Diane and Margaret, loving thanks for your love, understanding, and support in completing this study.

Finally, a special thanks to each other. Neither of us could have made it without the other.

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Abstract

A physiological data acquisition system and rotating chair were erected to allow future studies on the prevention of motion sickness induced by coriolis stimulation. Physiological monitoring equipment to measure pulse-to-pulse heart rate, gastric motility, respiration rate, and skin pallor were designed and built. This physiological monitoring equipment and commercially available equipment which measures skin surface temperature, galvanic skin reflex (GSR), and electomyogram (EMG) of superficial muscles were integrated into a programmable digital data acquisition system.

The programmable digital data acquisition system provides equivalent digital values for the analog outputs of the monitoring equipment at time intervals which can be chosen by an experimenter. These digital values are transmitted from the chair, through sliprings, to an output port where signal processing and data recording equipment can be attached.

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I Introduction

Background

In recent years a great deal of effort has been directed towards finding a way of suppressing motion sickness in aircrew personnel. Motion sickness, although an unpleasant inconvenience for the civilian traveler, can be a dangerous phenomenon when it affects aircrew personnel. Motion sickness can greatly reduce the operational effectiveness of a military unit. Even with recent advances in flight medicine and technology, little has been found which prevents motion sickness without sacrificing effectiveness (Ref 20:162). An innovative approach for reducing motion sickness incidence currently being investigated is the use of autogenic-feedback training, a form of psychotherapy which makes use of biofeedback techniques to train a person to control or alter his body's responses to certain stimuli.

Since 1979, the staff of the Neuropsychiatry Branch of the USAF School of Aerospace Medicine have used autogenic-feedback techniques, with an 80% success rate, to treat aircrew who have been disabled by chronic severe motion sickness. This treatment program currently requires

the full-time services of two flight surgeon psychiatrists and one biofeedback technician (Ref 17:118); this is very expensive and severly limits the number of aircrew who can receive the training. The use of elegant physiological monitoring equipment and computerized control is an alternative which would allow most of the training to be done by one biofeedback technician.

Problem

The basic problems involved in building a computerized motion sickness trainer are:

1) determing what physiological measurements have a high correlation with the onset of motion sickness;

2) developing a versatile and programmable data acquisition system which will allow the monitoring of the relevant physiological responses;

3) formulating a method of calculating a weighted sum of the relevant physiological measurements to determine a so-called "motion sickness factor" (This quantity will show the advancement of motion sickness symptoms and may need to be adjusted for each individual being trained.); and

4) developing a data processing system and system controller which will process the physiological measurements in real time to

determine the advancement of the subject's motion sickness symptoms. By utilizing this data, the system controller can control the motion sickness trainer.

Scope

The scope of this study will be to determine the relevant physiological responses and to develop the data acquistion system. A follow-on study will develop the data processing system and system controller, and the "motion sickness factor."

Assumptions

The basic assumption is that a computerized monitoring system can be a reliable substitute for the experience and senses of a trained psychiatrist who presently monitors the training and continuously estimates the state of nausea of the subject. Even if this assumption is not valid, the system will still be an extremely powerful data collection tool.

A second assumption is that autogenic feedback training is a valid method for preventing motion sickness. This assumption has been verified by a number of studies (Refs 17:118; 22:449). Even if this assumption is not valid and people simply lose their illness after prolonged exposure and "adaptation" to the provoking stimulus, the trainer will still be a very valuable tool for research, data collection, and motion sickness prevention training. We believe, as the USAF School of Aerospace Medicine has demonstrated, that a

combination of habituation to a provocative stimulus and biofeedback is a powerful treatment for motion sickness (Ref 17). At least until a so-called "silver bullet", a drug to prevent motion sickness without causing undesirable side effects, is developed this regime may well be the most effective treatment.

We do not make assumptions that the roots of motion sickness are biophysical and centered in the vestibular apparatus, as many do. We also do not assume that the roots of motion sickness are psychological. We do not even assume that the causes must be a combination of biophysical and neuro-psychological factors. These are the realm of those working in the fields of psychology, physiology, and related fields. We, as engineers, have designed and built a tool which will be useful to those studying the problem.

Summary of Current Knowledge

Most researchers believe that a degree of correlation exists between certain physiological responses and the onset or advancement of motion sickness; but, the responses can vary from subject to subject. The physiological responses which are typically monitored by instruments are heart rate, respiration rate, palor, galvanic skin response and intercostal muscle activity (Ref 22:450).

Both the USAF School of Aerospace Medicine and NASA-Ames Research Center are currently investigating the effectiveness of autogenic-feedback training in controlling motion sickness (Refs 3:118; 6:449). Each uses a motion

simulator to induce motion sickness in susceptible subjects. The subject can learn to control his symptoms by monitoring his physiological responses and being aware of the degree of his illness (Ref 3:119). If a particular response is identified as having a high correlation with his symptoms, biofeedback training can be used to control the response. As the training progresses the subject should be able to control the responses while in the simulator, thus controlling his motion sickness symptoms. The number of experiments necessary before a subject can control his responses to the stimuli is dependent on both the individual's ability to gain autonomic control of his physiological responses and his inherent susceptibility to motion sickness.

The Naval Aerospace Medical Research Laboratory has conducted tests in an effort to find a relationship between motion sickness symptoms and blood pressure, heart rate, and body temperature (Ref 10:211). Dr. Ashton Graybiel reported that Navy findings showed no evidence of any correlation between motion sickness and these physiological responses (Ref 10:214).

Dr. Graybiel's findings appear to be in sharp contrast to the apparent success of Dr. Patricia Cowings of NASA-AMES Research Center. Her efforts have yielded positive results in reducing motion sickness with autogenic-feedback training (Ref 22:450). The difference in the two findings appears to be a function of the approach. Dr. Graybiel was looking for

a measurable parameter to use as an indicator of the stage of motion sickness being experienced by the subject. Dr. Cowings allowed her subjects to find their own indicator corresponding to their individual body sensations (Ref 22:449).

In addition to biofeedback techniques, experimental work has been done with pharmacology and mechanical devices to combat motion sickness (Ref 18:148-152). Various drug compounds have been tested in the hope that motion sickness could be reduced without the subject exhibiting any unwanted side effects; this has yielded only limited success. Individuals seem to vary on both amounts of the drug needed and the displayed side effects (Ref 18:148).

There is currently no clear technique to prevent the occurrence of motion sickness. Each method in use today approaches the problem differently and with limited success. The autogenic-feedback training approach appears to offer some potential for providing a cure. The primary difficulty is finding the right set of indicators that correlate to an individual's motion sickness symptoms.

Approach

The approach this study took had the following steps:

1) a literature search was done in an attempt to understand the physiological responses that are most likely to be relevant;

2) a rotating chair with electronic servo-control was erected;

3) biofeedback and physiological monitoring equipment was installed on the rotating chair;

4) a versatile and programmable data acquisition system was designed and built using the National Semiconductor CIM computer.

II System Overview

The equipment to be erected and interfaced in this experiment is:

1. a custom built rotating chair which was previously used in experiments by the Air Force Aerospace Medical Research Laboratory (AFAMRL);
2. physiological monitoring equipment to measure pulse-to-pulse heart rate, gastric motility, respiration rate, and skin pallor;
3. a control input for the subject to provide what he judges to be his present physiological state according to training given to him by the experimenter;
4. Autogen Corporation biofeedback equipment which includes a skin temperature monitor, a dermograph, an electro-myograph and a display matrix; and
5. a programmable digital data collection and processing system which digitizes the output of the physiological monitoring equipment and the subject's input.

Overall System Configuration

The overall system configuration for taking measurements of an individual response, processing the data, and controlling the motion of the rotating chair is shown in figure II-1. The physiological monitoring equipment makes

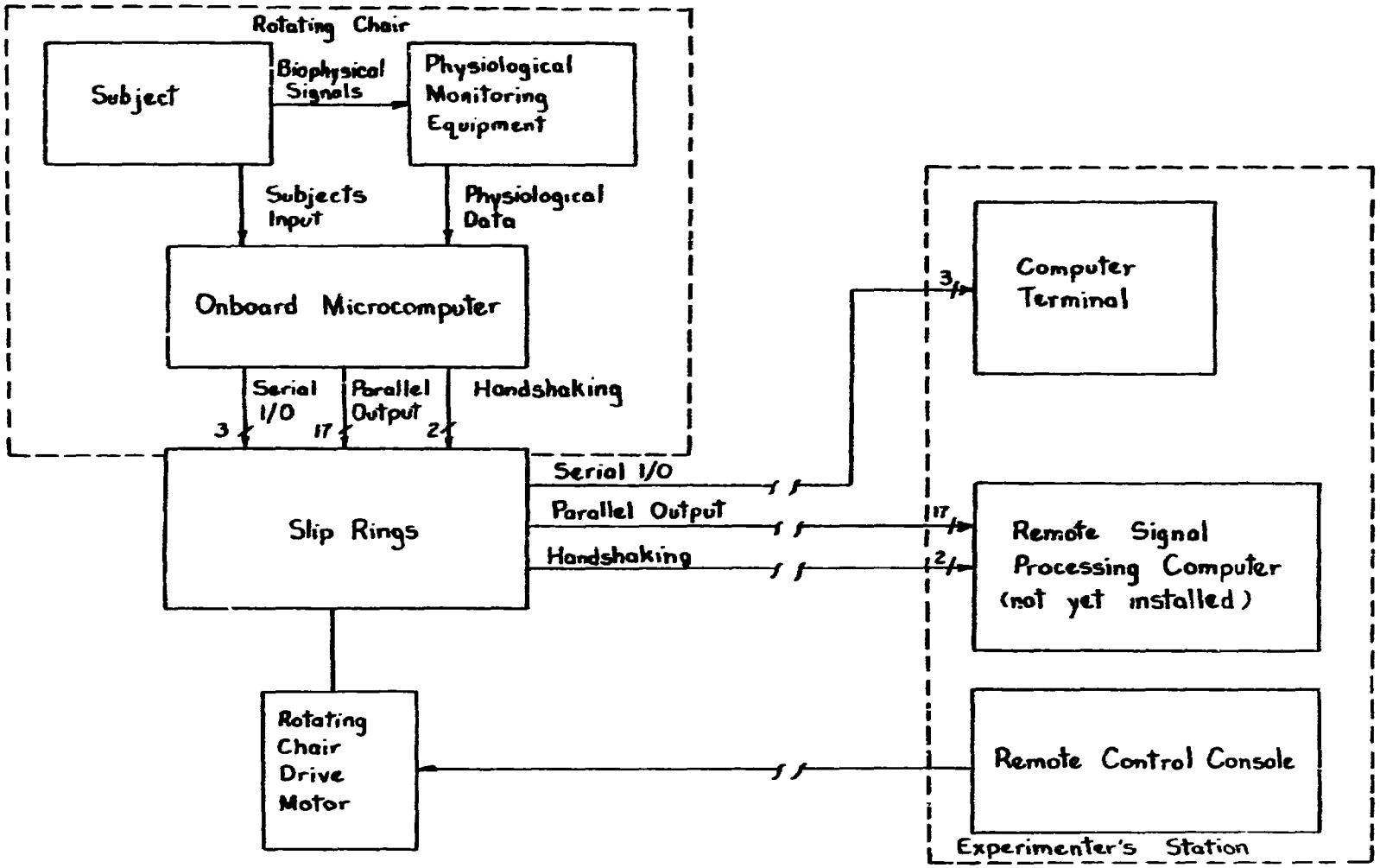


Figure II-1. Overall System Configuration

measurements on the subject. These measurements and the subject's input are digitized by the onboard microcomputer. The digitized measurements are passed through the sliprings to the remote signal processing computer, which will be installed during a follow-on thesis effort, at the experimenter's station. The experimenter's station also contains a terminal to allow the experimenter to "talk to" the onboard microcomputer and a control panel to allow the experimenter to control the motion of the rotating chair.

Rotating Chair.

A multiaxis motion simulator was configured to rotate about a single axis. An equipment rack housing the physiological monitoring equipment and onboard computer was attached to the support arms of the simulator as shown in figures II-2 and II-3. The pertinent operating instructions and cabling diagrams for the simulator are available in the manufacturer's documentation.

The remotely located console shown in figure II-4 controls and monitors both the axis position and the motion of the simulator. For this study the pitch control was disabled to allow the equipment rack to be attached directly behind the simulator cab. The yaw control was disabled because the chair was not designed to support the weight of both a subject and an equipment rack at non-zero yaw angles.

Physiological Monitoring Equipment.

Biophysical acquisition equipment was designed and built to augment the Autogen biofeedback equipment. The

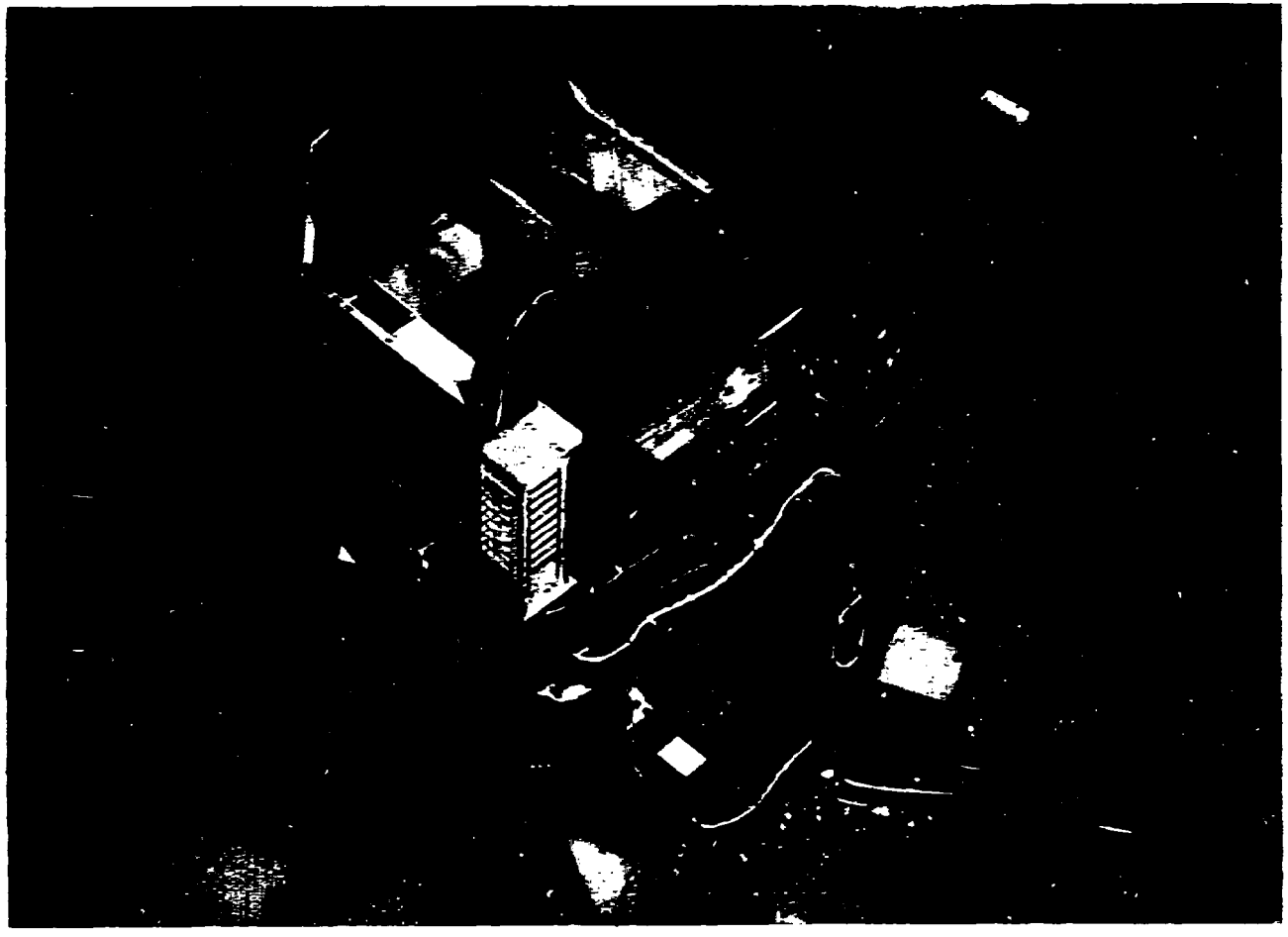


Figure II-2. Rotating Chair and Equipment Rack

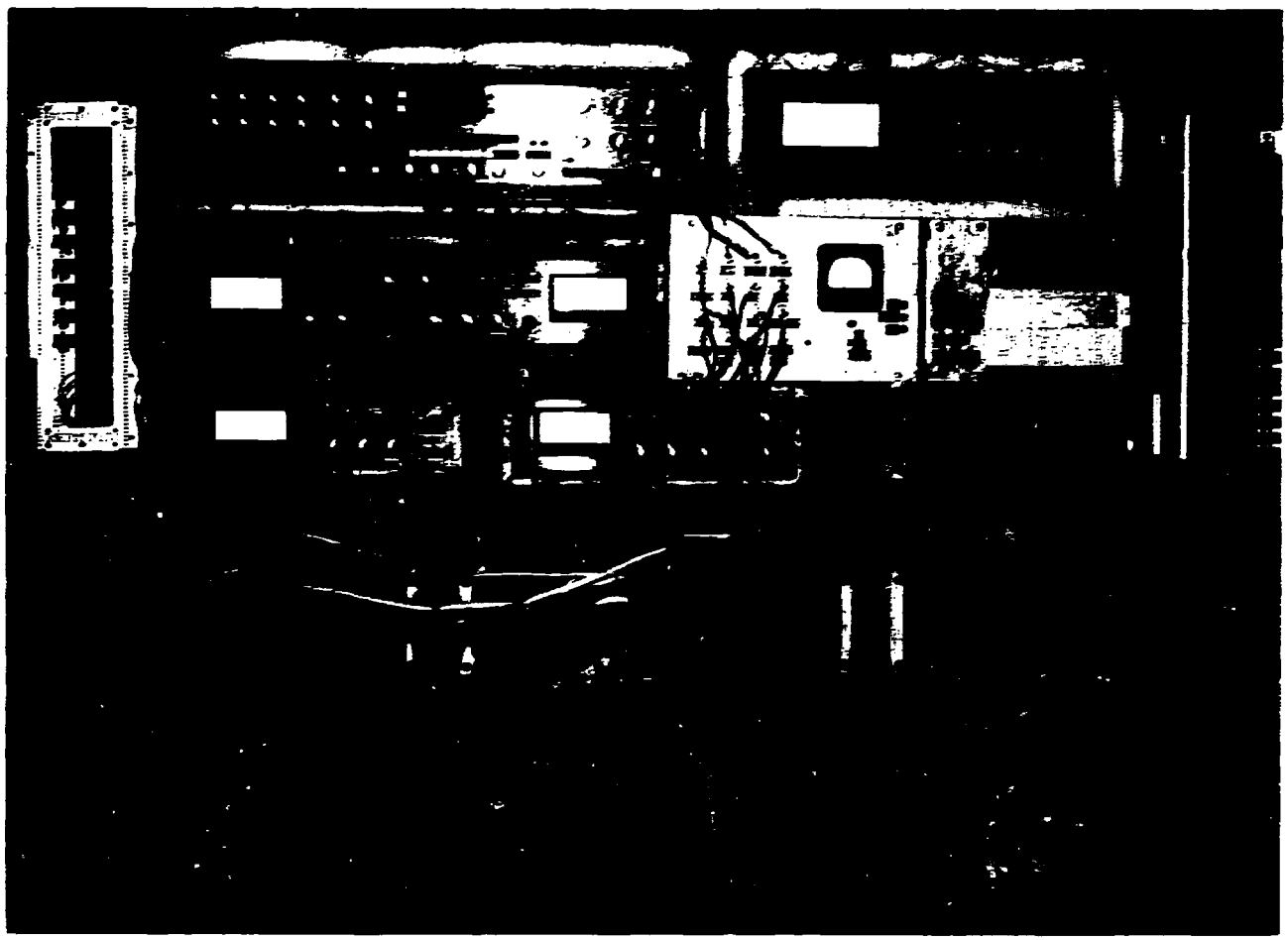


Figure II-3. Equipment Rack

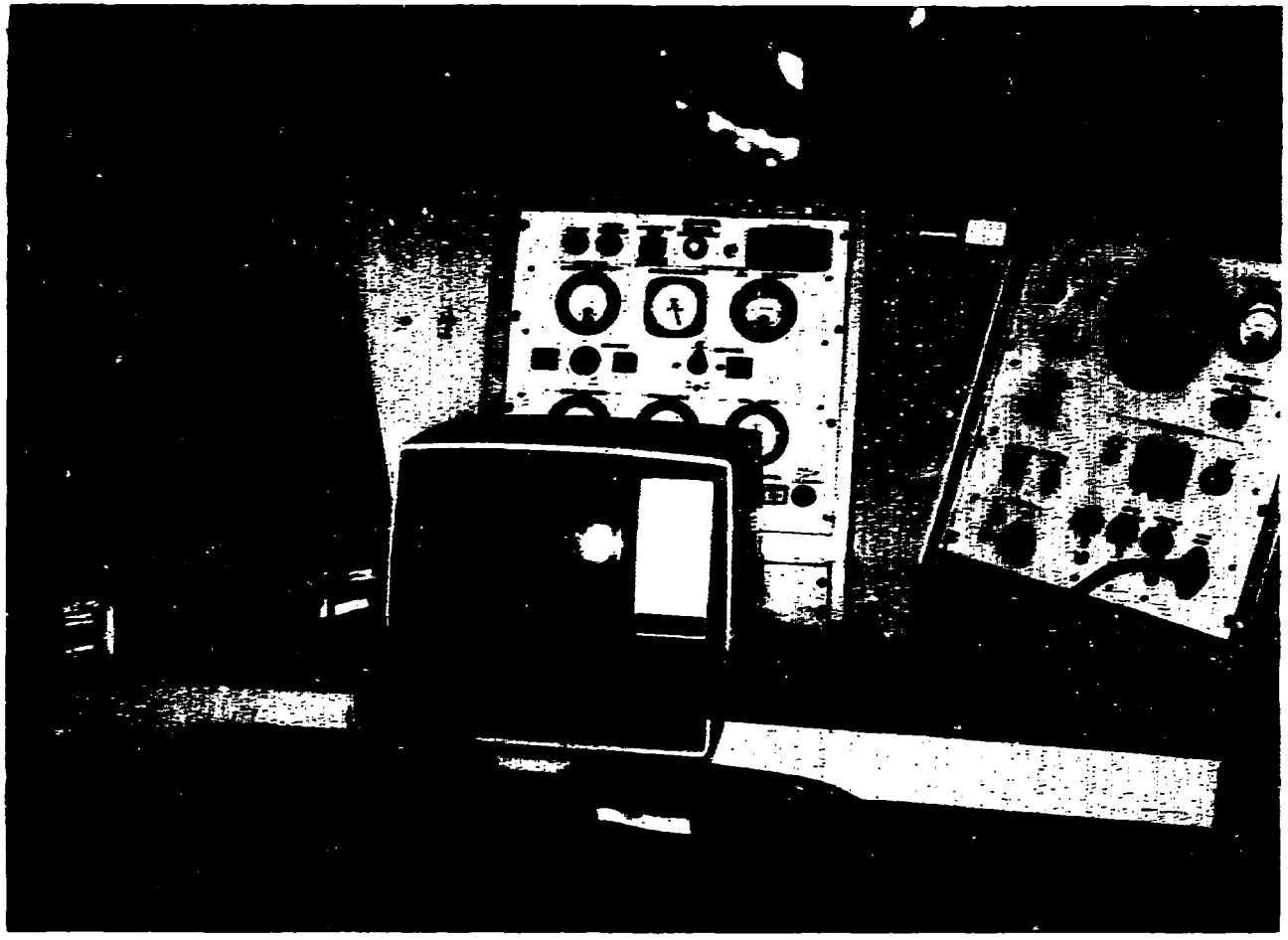


Figure II-4. Simulator Control Console

needed physiological data was pulse-to-pulse heart rate, gastric motility, respiration rate, and skin pallor. Each of the circuits was designed using commercially available components. A block diagram of the biophysical acquisition system is shown in figure II-2.

Pulse-to-Pulse Heart Rate. An electrocardiogram monitoring circuit was designed and built to detect the electrical impulses produced by the heart muscle. The output of this circuit is fed into an analog to digital converter, digitized, and sent to a remote terminal to be processed. The pulse-to-pulse heart rate will be derived in software from a continuous data stream. The accuracy will be a direct function of the sampling rate.

Gastric Motility. The gastric motility is a measurement of the activity level of the stomach. This activity level is believed to change as motion sickness progresses. It is this change in stomach activity that may correlate well with the onset of motion sickness.

The stomach activity level is monitored by a series of six electrodes arranged in a circle around a reference electrode in the middle of the abdomen. These electrodes pick up any low frequency electrical signals generated by the stomach. The six outputs are sent to the analog-to-digital converter to be individually processed.

Respiration Rate. The respiration rate is derived by transducers that estimate respiration volume by measuring chest and abdominal expansion. Two transducers were

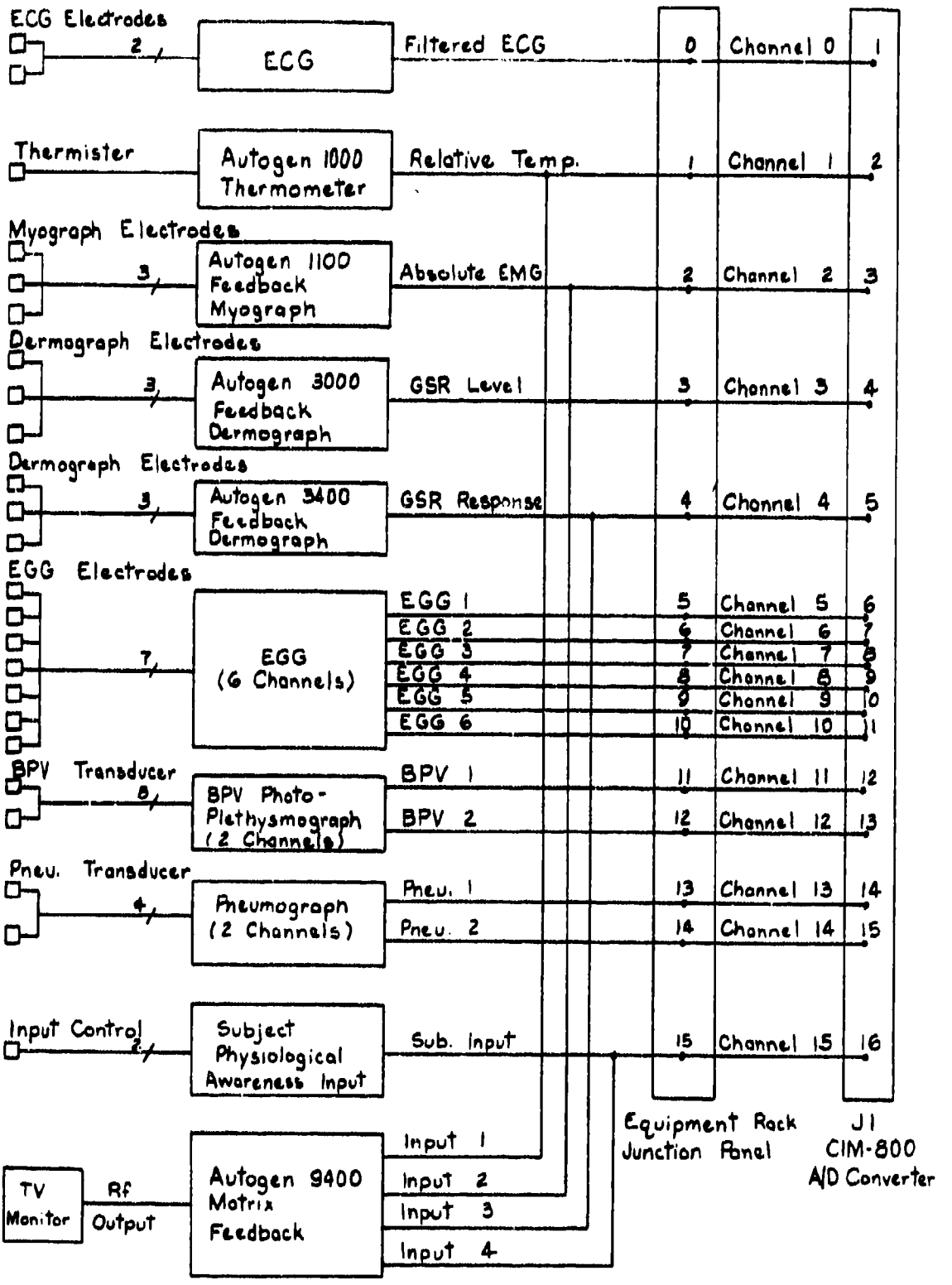


Figure II-5. Biophysical Acquisition System Block Diagram

fabricated to translate these expansions to a voltage level that could be processed by the computer. By measuring the breathing in this manner, the respiration type (chest or abdominal) as well as the respiration rate can be recorded. If there is a shift in the type of breathing at the onset of motion sickness, these transducers will be able to detect it.

Pallor. Skin pallor is a very subjective measurement. It was necessary to build a photo detection device to measure the blood flow to the face and extremities since it is the surface blood volume which is responsible for the variations in flesh tone. Two devices were built to optically detect the change in this surface blood flow; this corresponds to measuring the skin pallor. Using these devices will replace the subjective measurement with a consistent and computationally effecient one.

Subject Input.

A variable control was incorporated to allow the subject under test to input his perceived level of motion sickness. This output is fed back to the subject as a bar graph on the display while also being processed by the computer. With proper training the subject should be able to recognize his current state and associate it with the position of the bar graph display.

Autogen Corporation Biofeedback Equipment

The Autogen Corporation equipment includes a feedback thermometer, a feedback electromyograph, galvanic skin

reflex (GSR) feedback equipment, and a programmable display matrix.

The Autogen 1000 feedback thermometer measures skin surface temperature relative to some baseline temperature (Ref 11). Skin surface temperature is relatively easy to control with biofeedback techniques and can be used to build a subject's confidence in biofeedback training methods.

The Autogen 1100 Feedback Myograph measures the level of contraction or relaxation of a muscle. Feedback of the electromyograph helps a subject to learn how to relax the muscle being monitored. Feedback electromyography can help a subject learn to relax when confronted by anxiety producing stimuli, such as those which would normally lead to motion sickness.

The Autogen 3400 measures a subject's galvanic skin reflex (GSR) (Ref 13). GSR measurements are often associated with tension or anxiety. Achieving some control over GSR with biofeedback techniques is usually not very difficult for most people. GSR measurements are often associated with motion sickness and an often coincident sensation of "clammy" skin.

Programmable Digital Collection Equipment

An onboard microcomputer system, a National Semiconductor CIM microcomputer, samples the analog voltage outputs of the physiological monitoring equipment and the Autogen biofeedback equipment. The microcomputer system converts the sampled analog values into equivalent digital

values and outputs these digital values along with identifying headers to a parallel output board. The parallel output board transmits the digital data through the sliprings in the base of the rotating chair to signal processing circuitry.

By having the onboard digitizing and computing capability: the data from the collection equipment is conditioned to provide protection against transmission errors; the experimenter is provided with flexibility in choosing when to sample specific collection equipment outputs; and the computational complexity that is required of any signal processing circuitry is lowered.

III Biophysical Equipment Design

Additional biophysical acquisition equipment was designed and built to collect pertinent physiological data to be used in the motion sickness study. Measuring the pulse-to-pulse heart rate, gastric motility, respiration rate and skin pallor requires specialized instrumentation circuits (Ref 23: 1-29). The primary purposes of these circuits are to provide electrical isolation between the data processing system and the subject and to condition the biophysical signals prior to analog to digital conversion in the onboard computer. The nature of the signals and the maximum tolerable level of bias current through the subject-transducer interface made this a difficult task. This section will explain the instrumentation methodology chosen in this project.

Acquisition Hardware

The acquisition system consists of electrodes and transducers to extract the needed biophysical data from the subject, buffer amplifiers, and signal conditioning circuitry. All electrodes are pregelled disposable silver/silver chloride electrocardiogram monitoring electrodes; this allows the collection system to operate over an extended period without causing the subject discomfort.

Several transducers are also used in this system. In each case the transducer is electrically isolated from the

subject. This eliminates the need for observing the special precautions required for conductive electrodes.

A junction box is incorporated in the system to allow the electrodes and transducers to be applied to the subject while outside of the the motion simulator. Once the subject is seated in the simulator, the electrodes and transducers are connected to the junction box.

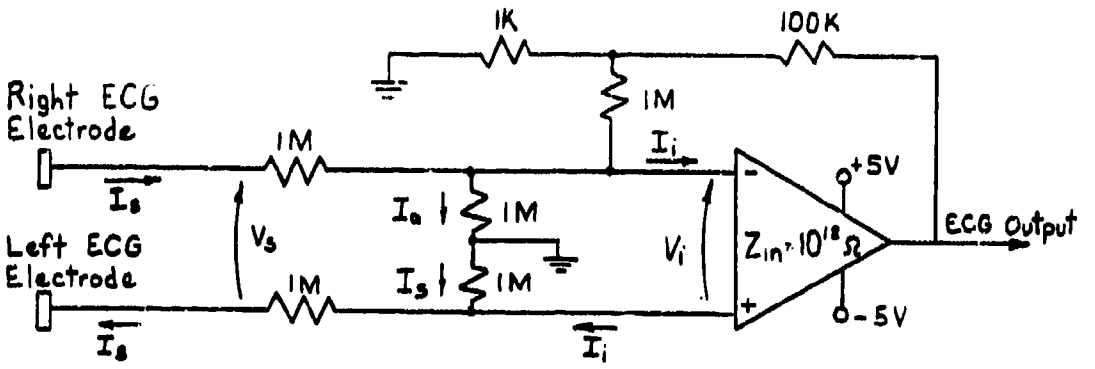
Each of the circuits is constructed on a single sided printed circuit board with an edge connector. The boards are housed in a card rack which is mounted on the left side of the equipment rack. The six circuits designed to derive the gastric motility (Ref 8) and the circuit designed to derive the heart rate have identical parts layout and were built on custom made printed circuit cards. The remaining circuits were built on two universal circuit boards with hard wired point-to-point connections. Each of the circuit boards have common power connections to prevent damage if a circuit card is inadvertently installed in the wrong location of the card rack.

Human Interface Difficulties. There are several inherent problems associated with interfacing human biophysical signals to a digital processing system. Concern for subject safety makes it necessary to limit the subject/transducer bias currents to a maximum safe level of 5 milliamperes (Ref 21) and to insure that artifacts created by any such currents can be properly handled by the collection equipment. It is also important to understand

that the desired biophysical signal levels are extremely small and very sensitive equipment is required to extract the data from an inherently noisy environment (Ref 23: 1-29).

In this study Intersil model ICL7650 chopper stablized operational amplifiers with extremely low DC bias current (10 picoamperes), high input impedance (typically 10^{12} ohms) and very high gain (120dB minimum) were used as buffer amplifiers to overcome these interface difficulties. The extremely low input offset voltage (1 microvolt) insures that a negligible electrode current will be sourced by the amplifier. An added benefit of these high impedance buffer amplifiers is the relative insensitivity to variations in the skin/transducer contact impedance.

The electrocardiogram (ECG) buffer amplifier circuitry is shown in figure III-1 and the electrogastogram (EGG) is shown in figure III-2. In figure III-1a the normal ECG electrode current produced by the difference in electrode potential was calculated and found to be 2.50 nanoamperes. This is far below the maximum safe current level of five milliamperes (Ref 21). The electrode current is recomputed in figure III-1b for the worst possible condition where the amplifier input offset voltage (Vi), due to amplifier failure, is raised to the supply potential. Even this extreme failure produces ar electrode current of only five microamperes, which is still far below the five milliampere safety limit.



V_s = 5 millivolt max $\quad I_i \approx 0$ Amps

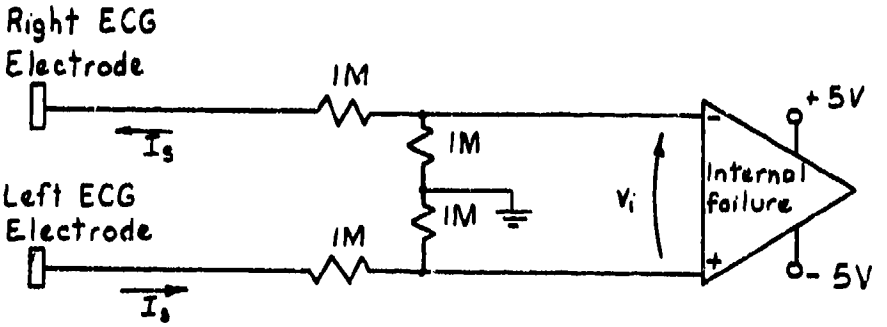
$V_i \approx 0$ Volts

$\therefore I_a = -I_s$

$V_s = I_s(3M) + I_a(1M) = I_s(3M) - I_s(1M) = I_s(2M)$

$I_{s\,max} = \frac{5MV}{2M} = 2.5$ nanoamperes

a. Maximum electrode current during normal operations

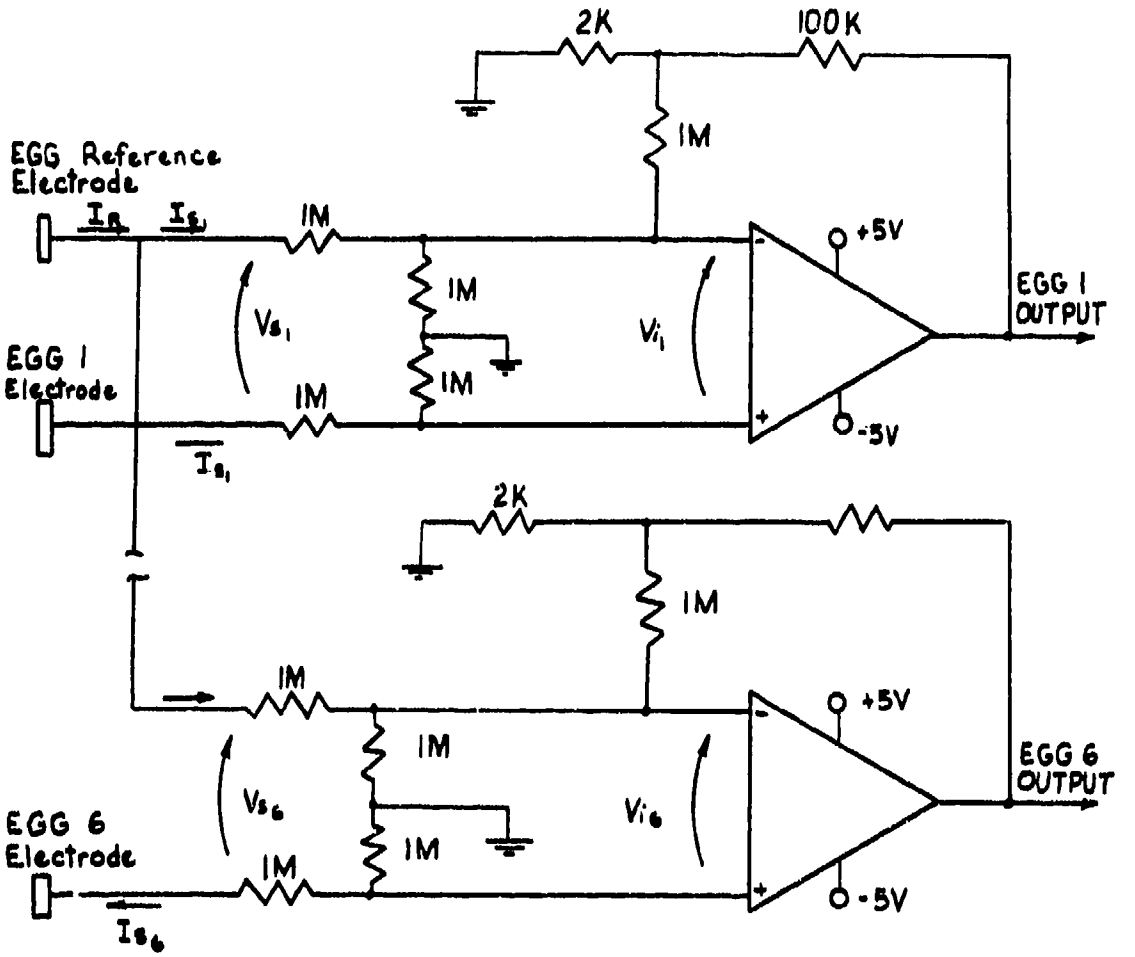


V_i = 10 volts (Maximum possible voltage)

$I_s \frac{10 \text{ volts}}{2M} = 5$ microamperes

b. Maximum electrode current with amplifier failure

Figure III-1. ECG Electrode Current Through Subject



V_s = 5 millivolt maximum $\qquad$ V_i = 0 volts

I_R = Reference electrode current

$= \sum_{i=1}^{6} I_{s_i} \leq 6\left(\frac{5mv}{2M}\right) = 15$ nanoamperes maximum

a. Maximum Electrode Current during normal operations

V_i = 10 volts (Maximum possible input voltage)

$I_R \leq 6\left(\frac{10 volts}{2M}\right) = 30$ microamperes

b. Maximum Electrode Current with amplifier failure

Figure III-2. EGG Electrode Current Through Subject

The electrogastogram (EGG) buffer amplifier circuitry is shown in figure III-2a for the normal operating conditions and in figure III-2b for the worst case failure mode of operation. The reference electrode carries the sum of all the other electrode currents and therefore has the largest current intensity. It was found that the maximum current intensity for the reference electrode during normal operations was fifteen nanoamperes and the extreme failure mode produced only thirty microamperes. Again this is far below the maximum safe level of five milliamperes. It can be concluded that the ECG and EGG acquisition circuits present no danger to subjects under test and since these are the only designed circuits which make direct contact with the subject's skin through an electrode, the entire collection system can be regarded as safe.

Power Requirements. Power supplies for such a large instrumentation effort are also a problem. The use of individual power supplies is certainly simpler and less expensive but can introduce unwanted ground loops which would severely limit the overall effectiveness of the collection system. A twelve volt, twenty ampere-hour lead acid battery was chosen to meet the power requirements of the National Semiconductor CIM 800 computer and supply most of the power for the instrumentation circuits. A battery charging circuit is included as an integral part of the power supply system.

The charging circuit was designed around a MC1723

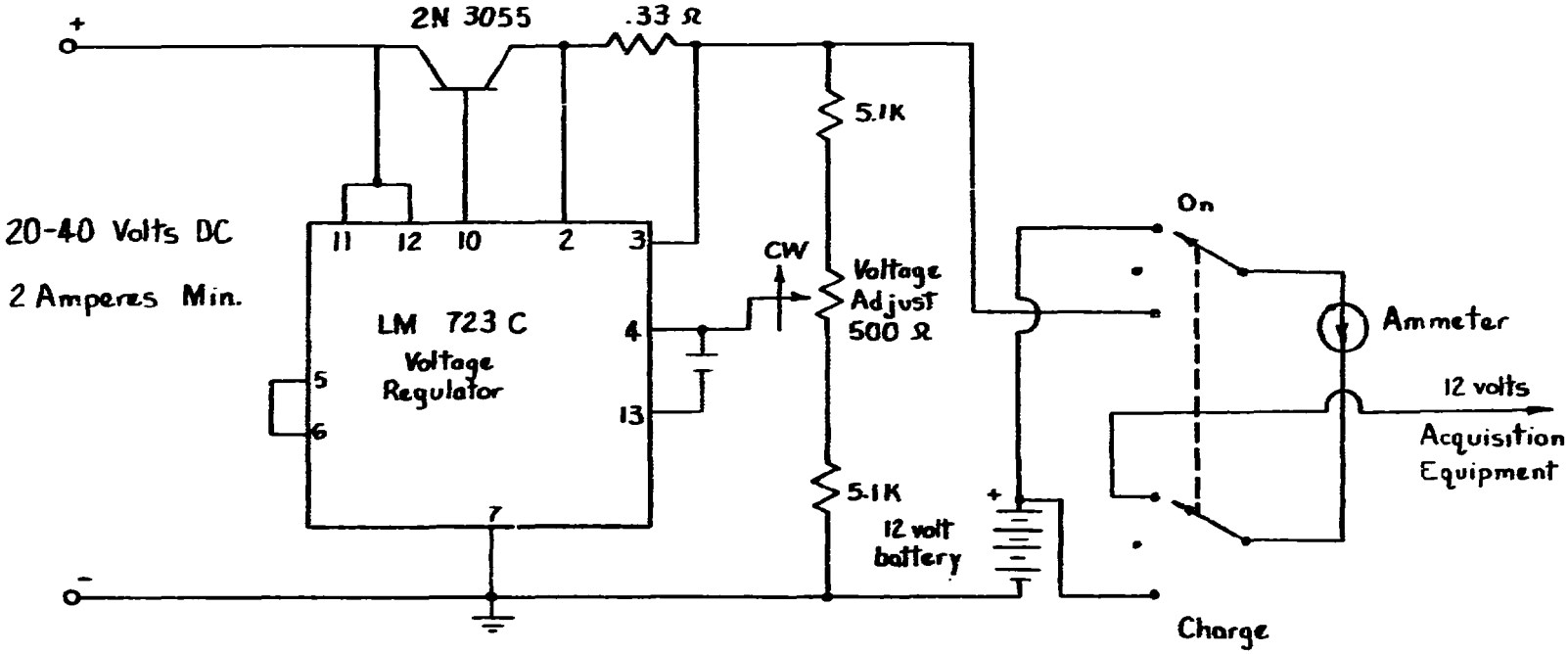


Figure III-3. Battery Charging Circuit

monolithic voltage regulator (Ref 25: 132-137) as shown in figure III-3. Any 20-40 volt DC power supply capable of sourcing at least two amperes can be used as an input to the battery charger. The output of the charger is voltage limited to 13.85 volts and current limited to two amperes. The battery is kept from operating in a deep cycle mode, since both the normal load on the battery and the charging current are two amperes or less; this will extend the useful life expectancy of the battery. A charging voltage adjustment potentiometer and test point are incorporated in the design to assist in maintaining the proper charging voltage over the life of the battery.

In order to be able to monitor the battery charging or discharging current, a current meter and double-pole triple-throw switch arrangment were utilized as shown in figure III-3. Both charging and discharging currents are seen as a positive deflections on the meter with this configuration. The battery output is disabled during the charging operation to protect the computer from a poorly filtered charging source. The center (off) position of the switch completely isolates the battery from all circuits. The battery switch should be kept in the off position except during system use or battery charging.

A secondary twelve volt dry cell battery is incorporated as the negative supply for the instrumentation circuits only. Both the primary twelve volt supply and the negative twelve volt supply were used to derive the bipolar

five volt source needed by the ICL7650 buffer amplifiers in the instrumentation circuits. Since the load on the five volt supplies was determined to be a hundred milliamperes or less, a MC7805C was used to produce the positive five volts and a MC7905C was used to produce the negative five volts.

Pulse-to-Pulse Heart Rate

The pulse-to-pulse heart rate will be derived in software from a continuous data stream of sampled electrocardiogram (ECG). The electrode placement for deriving the electrocardiogram and electrogastogram signals is shown in figure III-4. A block diagram of the ECG circuit and the measured passband characteristic curve are shown in figure III-5. The ECG is detected using two disposable silver/silver chloride electrodes attached as shown in figure III-4, diagonally opposed across the front of the chest to measure the induced skin potential produced by the frontal plane ECG vector. The output of the electrodes is fed into a chopper stabilized buffer amplifier followed by a unity gain bandpass filter with a passband of .05-20 Hertz. The bandpass filter is composed of a second order high-pass filter followed by a third order low-pass filter. Both filter sections were unity-gain Sallen-Key configurations with the damping chosen to be 1.414 to achieve a maximally flat response (Ref 16). The high-pass section was chosen as the first stage of the bandpass circuit in order to provide the input of the low-pass section with a low impedance return to ground; thus driving

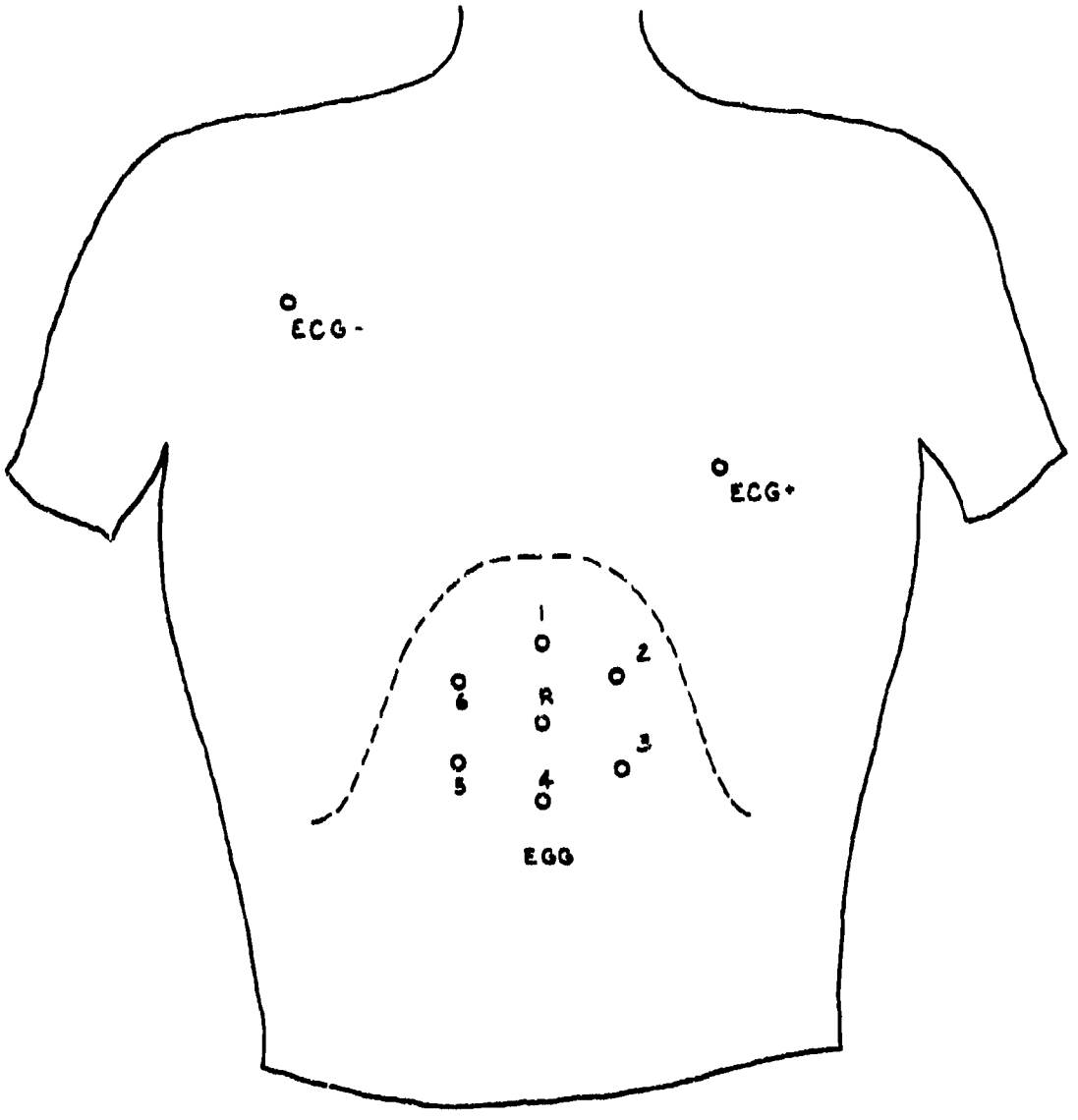
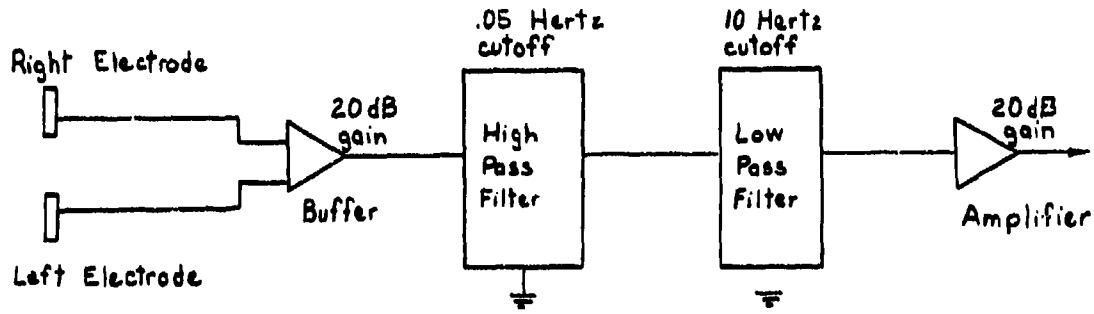
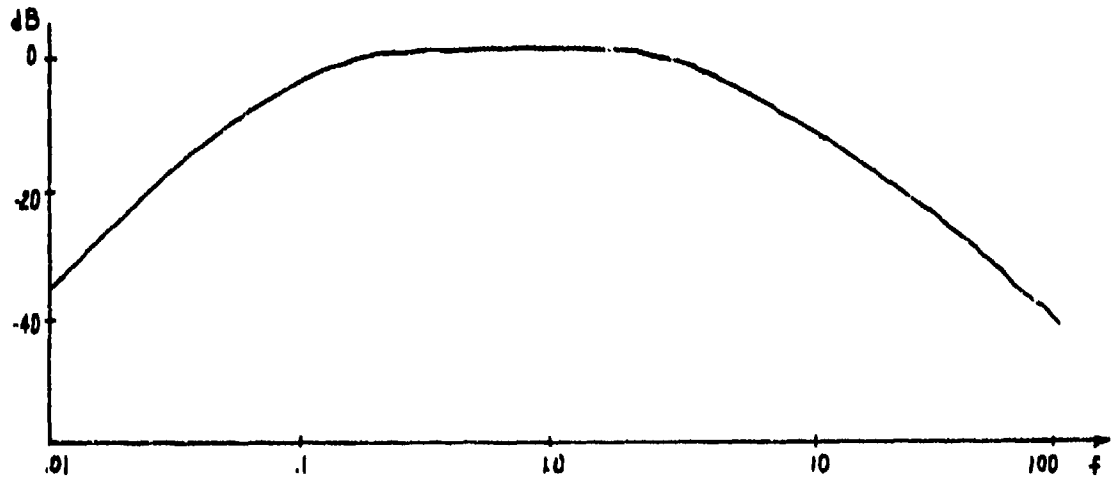


Figure III-4. Biophysical Electrode Placement



a. ECG Block Diagram



b. ECG Filter Response

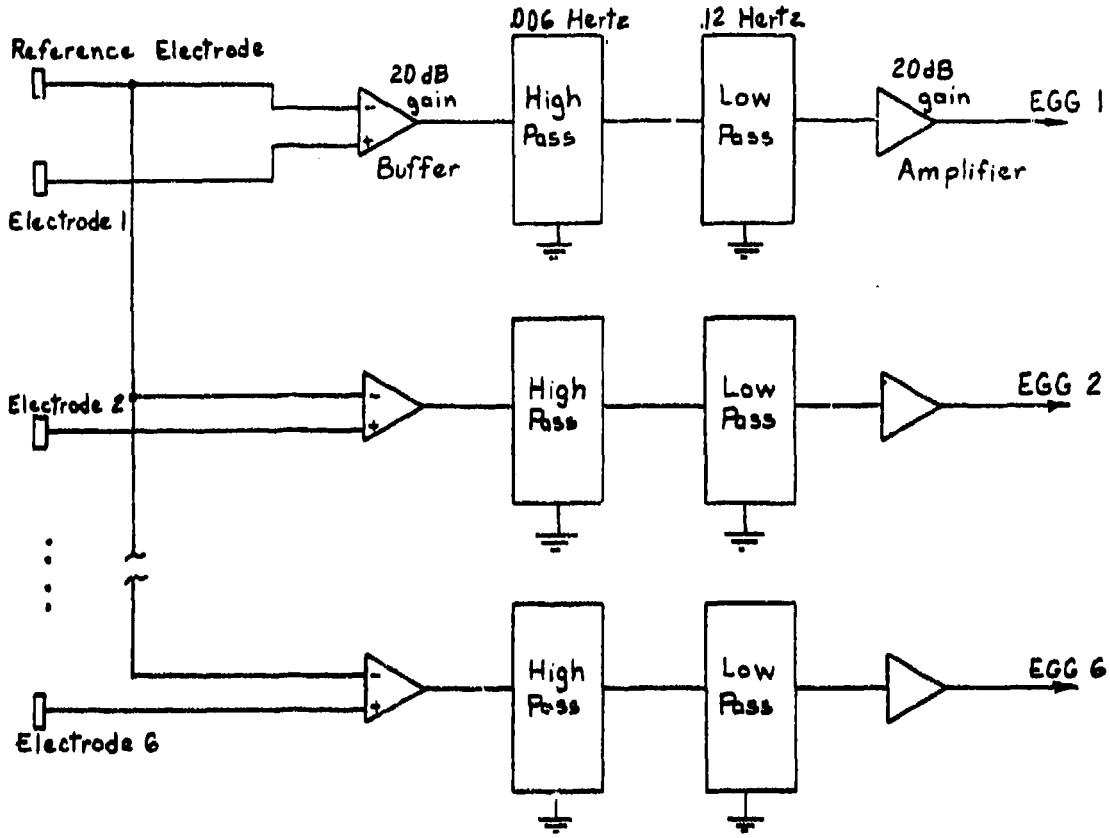
Figure III-5. ECG Circuitry

the low-pass section with a low impedance source (Ref 16). Since the only information to be derived was the time interval between the QRS complexes of the ECG, the filter high frequency cutoff was set to twenty Hertz to eliminate any possible sixty Hertz interference. A plot of the ECG pulse train is shown in figure F-1 of Appendix F.

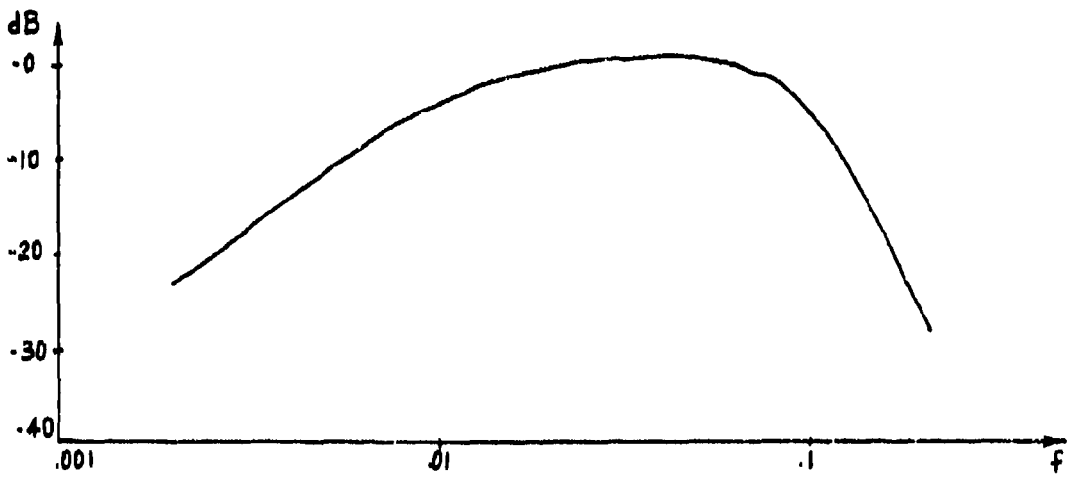
Gastric Motility

One of the prime indicators of the onset of motion sickness is the change in the low frequency voltage waves produced by the stomach (Ref 8). The frequencies of this wave, one third cycle per minute and one cycle per minute as observed by the NASA-Ames facility (Ref 8), require a filter passband of .006-.12 Hertz. If the signal can be recorded and correlated to motion sickness, then it may prove to be an important factor.

In order to extract the Electrogastogram (EGG) from the body, a circuit similar to the one used for the ECG was designed and built. A block diagram of the EGG circuitry is shown in figure III-6. The bandpass filters were designed with a second order high-pass section followed by a third order low-pass section similar in structure to the ECG circuit design. Again the Sallen-Key unity gain filter design was used. Unlike the ECG circuit, the damping of the low-pass section was increased to approximately four in order to further smooth the passband at the cost of a sharp upper frequency cutoff (Ref 16). The measured filter response curve is shown in figure III-6.



a. EGG Block Diagram



b. EGG Filter Response

Figure III-6. EGG Circuitry

The electrodes were configured as shown in figure III-4 with the reference electrode in the center of the others. This reference electrode is connected to the inverting input of all the EGG buffer amplifiers to cancel out the stray signals present at the abdomen. Sampled outputs of the EGG circuitry are shown in figure F-2 of Appendix F.

Respiration Rate

There are thought to be some changes in the respiration pattern at the onset of motion sickness. Two identical transducers were developed to distinguish between respiration by chest expansion and respiration by diaphragm displacement. One transducer is positioned around the top of the chest and the other is positioned around the abdomen, just below the navel. Each transducer, made of two sliding, interleaving plexiglas plates, resembles a slide rule. One plate is held stationary with respect to the chest, for example, and the other is allowed to move portionally to the expansion of the chest cavity.

Movement of the plate causes a porportional change in a variable capacitor which is mechanically linked to the plate. Since the capacitor is an integral part of an astable multivibrator, the plate displacement also causes a porportional change in frequency. The oscillator has a frequency of five kilohertz with the transducer compressed and a frequency of approximately eight kilohertz when the transducer is fully expanded. The output of the oscillator is fed into a National Semiconductor frequency-to-voltage

converter. The signal conditioning circuitry performs a level shifting and a gain adjust function so that the output voltage is zero when the transducer is compressed and ten volts when fully expanded.

The monitoring of the respiration could have been accomplished using transducers made from sliding potentiometers, but the reliability of the device under constant operation would be highly questionable. No such problem exist with variable capacitors. A diagram of the transducer is shown in figure III-7a and a block diagram of the circuit is shown in figure III-7b. Sampled outputs of the pneumographs are shown in figure F-1 of Appendix F.

Skin Pallor

Another physiological change that accompanies the onset of motion sickness is increased skin pallor, especially of the face (Ref 8). In clinical studies this has always been a highly subjective measurement on the part of the observer. Two photoelectric blood plethysmographs were designed and built to measure the relative blood pulse volume in the surface tissue of the face and extremities. Each was designed using a Motorola MLED 930 infrared-emitting diode and a Motorola MRD photo Darlington transistor for extra high sensitivity. A sectional view of the two plethysmograph transducers and the corresponding photo transistor collector characteristic curves are shown in figure III-8.

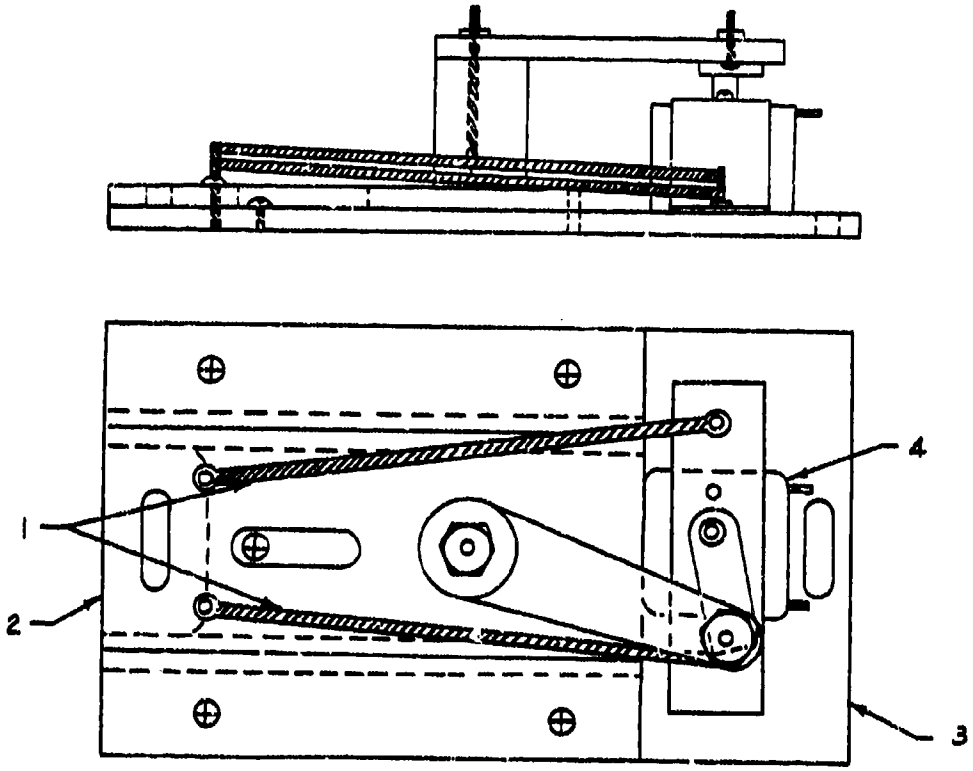
The photo-plethysmograph for detecting the change in

blood volume to the face was constructed as shown in figure III-9a. The block diagram is shown in figure III-9c. Both photo transistor and light source are mounted in a phenolic disk which is one-eighth inch thick and one and one-half inches in diameter. A narrow beam of infrared light is used to illuminate the facial tissue at an incidence angle of forty-five degrees. On the other side of the disk, the photo transistor is aimed at a forty-five degree incidence angle such that the two beam patterns form an intersection one-eighth of an inch below the center of the disk. In this manner light reflected by the blood in the tissue will be intercepted by the transistor.

Two gain adjust variable resistors are incorporated in the photo-plethysmographs to allow this circuit to be used on groups of subjects with a wide varity of skin pigmentation. The first resistor sets the gain of the photo transistor to compensate for different skin pigmentation. The second resistor adjust the overall gain of the circuit to achieve an unsaturated baseline response.

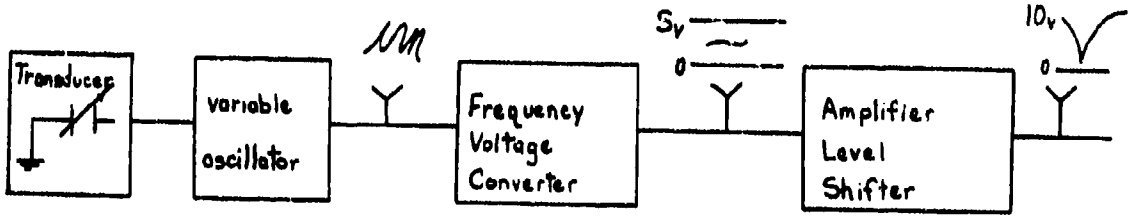
A signal flow block diagram for the blood pulse volume photo-plethysmograph and the signal representations at each step are shown in figure III-9.

The output of the transducer is fed into a series of high-pass and low-pass filters; this effectively produces a bandpass filter with a passband response of 0.25 to 5 hertz. The low frequency cutoff of the filter eliminates any DC component of the received signal. The five hertz high



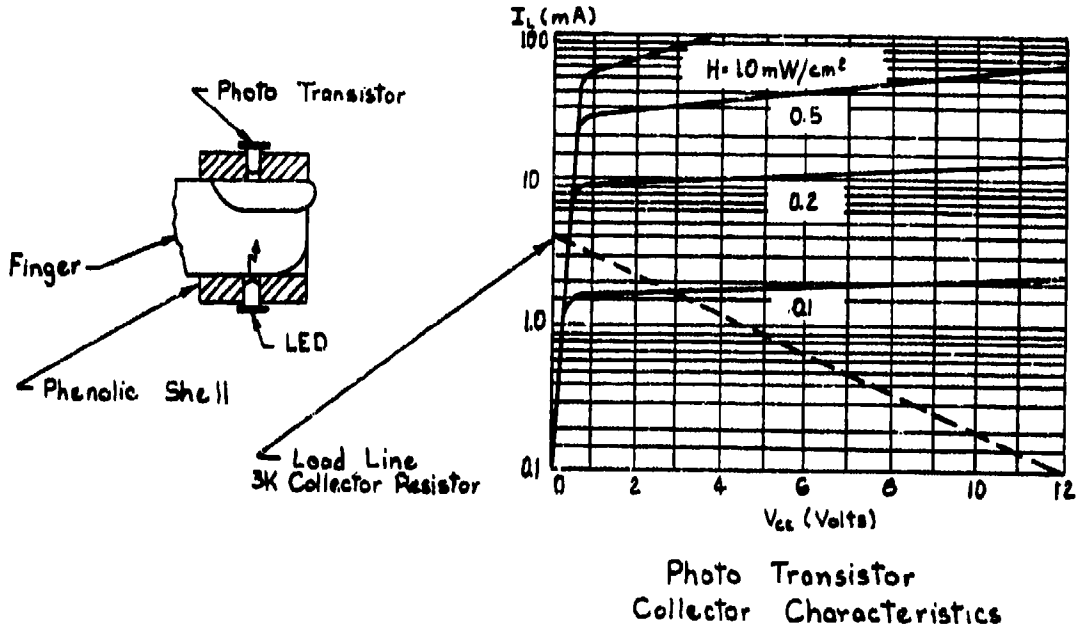
1	Return Springs
2	Slide
3	Housing Plate
4	Capacitor

a. Transducer

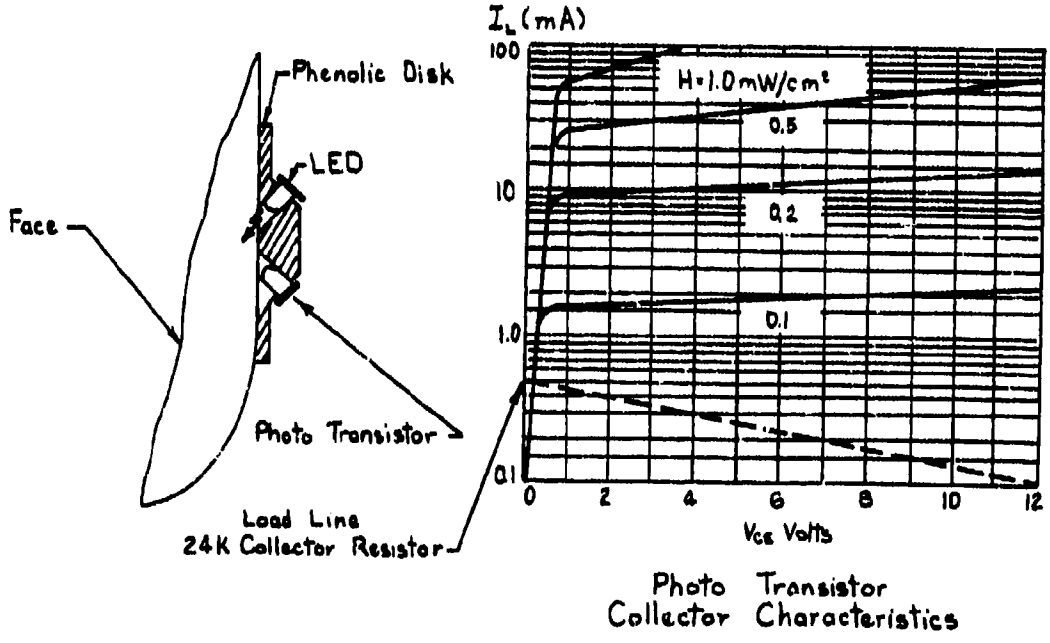


b. Signal Block Diagram

Figure III-7. Pneumograph

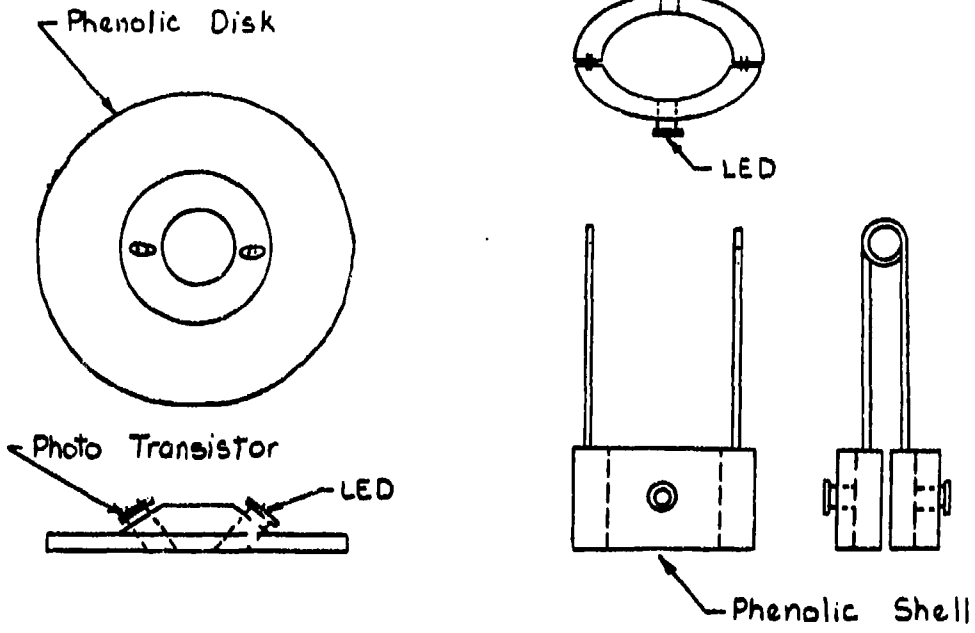


a. Finger Transducer



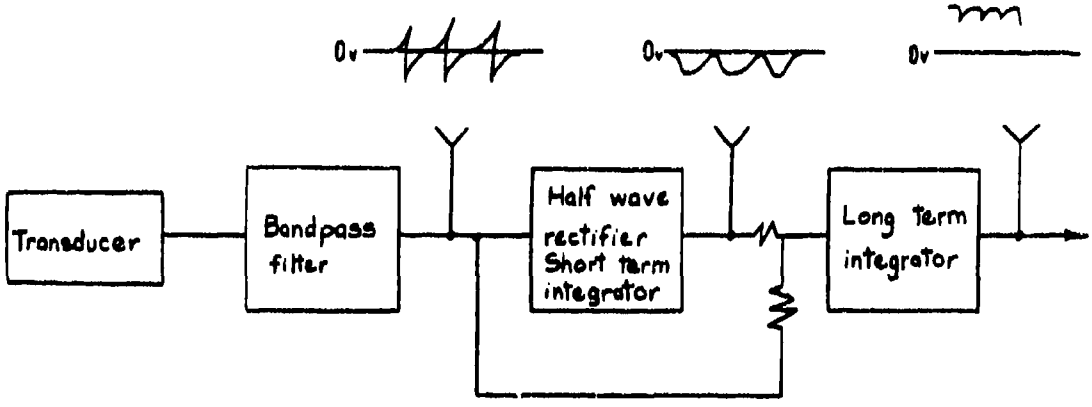
b. Facial Transducer

Figure III-8. Photo-plethysmograph Transducers (Ref 18)



a. Facial Transducer

b. Finger Transducer



c. Signal Flow Block Diagram

Figure III-9. Blood Photo-plethysmograph

frequency cutoff preserves enough information to determine the pulse-to-pulse changes in the blood pulse volume. A damping value of three is used to produce a smooth passband response curve (Ref 16). The output of the bandpass filter is the blood pulse signal.

The blood pulse signal is passed through a half wave rectifier which rectifies and stretches the pulse with a short time integration network.

The output of the half-wave rectifier is fed to a long term integration circuit. In order to preserve the pulse-to-pulse blood volume measurement, the integrator is reset to a reduced value at the begining of each pulse. This is done by summing the unstretched pulse from the bandpass filter circuit with the output of the half-wave rectifier.

The output of the long term integrator is a DC voltage level. This level has a significant relationship to the volume of the blood pulse being monitored.

The photo-plethysmograph used for measuring the blood volume to the extremities detects changes in blood pulse volume by passing the infrared light directly through the little finger and detecting the corresponding changes in intensity. The electrical circuit configuration of the extremity blood plethymograph is identical to the facial blood plethysmograph, but the physical structure is different. The photo transistor and light source are mounted on hollow cyclinder halves which are held in contact

by a spring. An opaque cloth sack was made to eliminate any stray light from interfering with the results. A diagram of the transducer is shown in figure III-8b. Sampled outputs of the blood pulse volume photo-plethysmographs are shown in figure F-1 of Appendix F.

The biophysical acquisition equipment developed for this study along with the available Autogen biofeedback equipment should provide the necessary monitoring of the important physiological signals. The integrity of the data will be preserved by the digital computer. The versatility of the collection system allows it to adapt to new collection requirements as they appear.

IV Digital Processing Hardware

The motion sickness trainer is equipped with onboard digitizing hardware to insure data integrity. Passing the analog voltage outputs from the collection devices directly through the slip rings could distort the signals with noise and attenuation, especially in a variable field condition. The integrity of the data is protected by sampling and digitizing the analog voltage outputs from the collection devices onboard the chair and passing the digital values through the slip rings to the processing equipment. Since the signal processing equipment is digital, we can input the digital values of the signals directly into the Masscomp computer. This frees the Masscomp computer to perform more significant real-time signal processing and control tasks.

Overview of the On-Board Hardware

The functions of the digitizing hardware are to:

1. sample the analog outputs of the physiological measuring devices at intervals which the experimenter specifies in a program;
2. digitize the sampled outputs with 12 bits of resolution;
3. affix a four bit header which identifies the sampled responses with the digitized values; and
4. transmit the 16 bits of data with a parity

check bit through a set of slip rings with two-way handshaking.

The foundation of the digitizing hardware is a National Semiconductor CIM-800 microcomputer system (Ref 2;3;4;5;6;7) which is mounted on the rotating chair. The CIM-800 system consists of the following boards which are interconnected by a common bus called the CIMBUS:

1. a CIM-802 Microcomputer Board with an onboard prom that holds the monitor program from National Semiconductor;
2. a CIM-201 Serial I/O Board that communicates with a remote terminal via a RS-232 link;
3. a CIM-411 Analog Input Board which performs analog to digital conversion functions;
4. additional voltage regulator and memory expansion boards; and
5. a parallel output board, the operations of which are described later in this chapter.

The CIM-201 Serial I/O board allows a remote terminal to pass programming and instructions to the digitizing hardware via a RS-232 link. The RS-232 link passes data through slip rings in the base of the rotating chair.

The CIM-411 Analog Input Board is the interface between the analog physiological measuring devices and the CIM-802 microcomputer board. Under the control of an experimenter written program, as the example in Appendix E, the analog

input board individually samples the sixteen analog physiological response channels and converts the received voltages into 12 bit digital values which can be read by the microcomputer board.

After the 12 bit value has been read by the microcomputer board, the microcomputer can store the value and order the analog input board to sample another channel. As the analog input board cannot instantly convert sampled analog voltages into digital values, the normal sequence of events is:

1. a value is read from the analog input board and stored by the the microcomputer;
2. the microcomputer selects another analog channel and orders the analog input board to sample the instantaneous voltage on that channel;
3. the microcomputer processes data while the analog input board independently performs the directed analog to digital conversion;
4. after the analog to digital conversion is completed by the analog input board, the microcomputer reads the result of the conversion at its leisure; and
5. the cycle repeats.

A four bit header which identifies what channel the data was sampled from is attached to the 12 bits of A/D data during step three of the above sequence of events. These 16

bits are then output to the memory-mapped parallel output board and transmitted through the slip rings.

The parallel output board, parallel data transfer, and the remote receiver test board will be the subject of the remainder of this chapter.

Description of Parallel Output Board signals

The parallel output board allows the on-board CIM microcomputer to send 16 bits of data, together with a parity check bit and two-way handshaking signals, through the slip rings to the signal processing equipment that is not mounted on the chair.

The 16 bits of data consist of the four most-significant bits which identify the collection device being sampled and the 12 least-significant bits which carry the digital value of the sampled collection device analog output voltage, within the range of -5 to +5 volts. This data format is easy to achieve in software in the onboard microcomputer because of the format in which data is passed between the onboard computer and the analog input board.

When the microcomputer sends an instruction to the analog input board to sample the instantaneous value of the analog voltage present on a specified channel,the instruction includes a number, 0 through 15, which identifies the specified channel.

The digitized sampled value is in two byte format when the microcomputer board reads it from the analog input board

(Ref 4). The first byte contains the eight least significant bits of the conversion result. The second byte holds the most significant four bits of the conversion result in the four least-significant bits of the byte, with the four most significant bits of the byte being all ones when the conversion is complete. Since the four most-signficant bits are all ones, it is easy to logically and these four bits with the number of the channel that was sampled.

The parallel output board has a hardwired two line handshaking circuit. The H1 handshaking signal is sent out in parallel with the 16 data bits and a parity check bit. The H1 signal informs the remote signal processing equipment that new data is available. The remote signal processing equipment transmits a data accepted handshaking signal, H2, when the data is accepted. When the H2 handshaking signal arrives at the parallel output board, the H1 signal is shut off until the next set of data is output from the parallel output board.

The data from a current transmission is lost if the H2 signal, acknowledging data reception, is not received at the parallel output board before the data from the next sampled channel is output to the parallel output board. This is necessary to prevent an error in one transmission from destroying the timing betwween samples. The alternatives would unnecessarily complicate the data acquisition software. A more reasonable approach is to have the remote

signal processing computer smooth the data for a channel if a transmission is missed.

An even parity check bit is generated in hardware on the parallel output board. This parity bit is a logic "0" or a logic "1" according to the number of logic "1"s in the 16 data bits. This parity check bit protects the 16 data bits from any single bit errors that might be generated in the sliprings or transmission lines.

Parallel Output Board Circuit Description

The logic diagrams for the parallel output board are shown in figures IV-1, 2, 4, and 5. An assembly drawing which shows the integrated circuit pack placements is shown in Appendix C. An integrated circuit listing is provided in table IV-1. A signal line interconnection listing, giving all pin-to-pin connections, is in Appendix C.

Input Buffers. The 4010 buffers (U1, U2, U3, U4, and U6) in figures IV-1, 2, and 4 raise the current levels of the 27 CIMBUS signals used by the parallel output board to TTL levels. These buffers are required because the CIMBUS signals are at CMOS levels, which would most likely be inadequate to drive the cascaded TTL logic on the remainder of the parallel output board.

Board Select Circuitry. The parallel output board is hardwired to correspond to the memory-mapped hexadecimal port addresses of FD and FE. Since the on-board microcomputer places the port address (00 through FF are the

possible memory-mapped I/O port addresses) on the CIMBUS in each of the bytes A0 through A7 and A8 through A15 (Ref 4), bits A2 through A7 and A10 through A15 will always be in a logic high state when the board is addressed. The bits input to the 13 input nand gate, U5, produce a logic low "select" pulse that signals the remaining select logic that the board is possibly being addressed.

The remainder of the board select circuitry is shown in figure IV-2. This circuitry is not enabled unless the "select" pulse, the active low CIMBUS write line, and the active low CIMBUS port input-output line are all simultaneously logic low.

The timing diagram for the board select circuitry is shown in figure IV-3. The logic equations for the latch-A enable signal and the latch-B enable signal are:

$$\text{PA Enable} = \overline{\text{Select}} \cdot \text{WR} \cdot \text{I/O} \cdot \text{A0} \cdot \overline{\text{A1}} \cdot \overline{\text{A9}}$$

$$\text{PB Enable} = \overline{\text{Select}} \cdot \text{WR} \cdot \text{I/O} \cdot \overline{\text{A0}} \cdot \text{A1} \cdot \overline{\text{A8}}$$

A latch-A enable signal is generated when the three aforementioned signal lines and address bits A1 and A9 are all at a logic low level. The latch-A enable signal clocks the eight data bits presently on the CIMBUS into U11, a 74374 hex-latch as shown in figure IV-4.

A latch-B enable signal is generated when "select", write, port I/O, and address bits A0 and A8 are all at a logic low level. The generation of the latch-B enable initiates the handshaking sequence as shown in figure IV-2 and clocks the eight data bits presently on the CIMBUS into

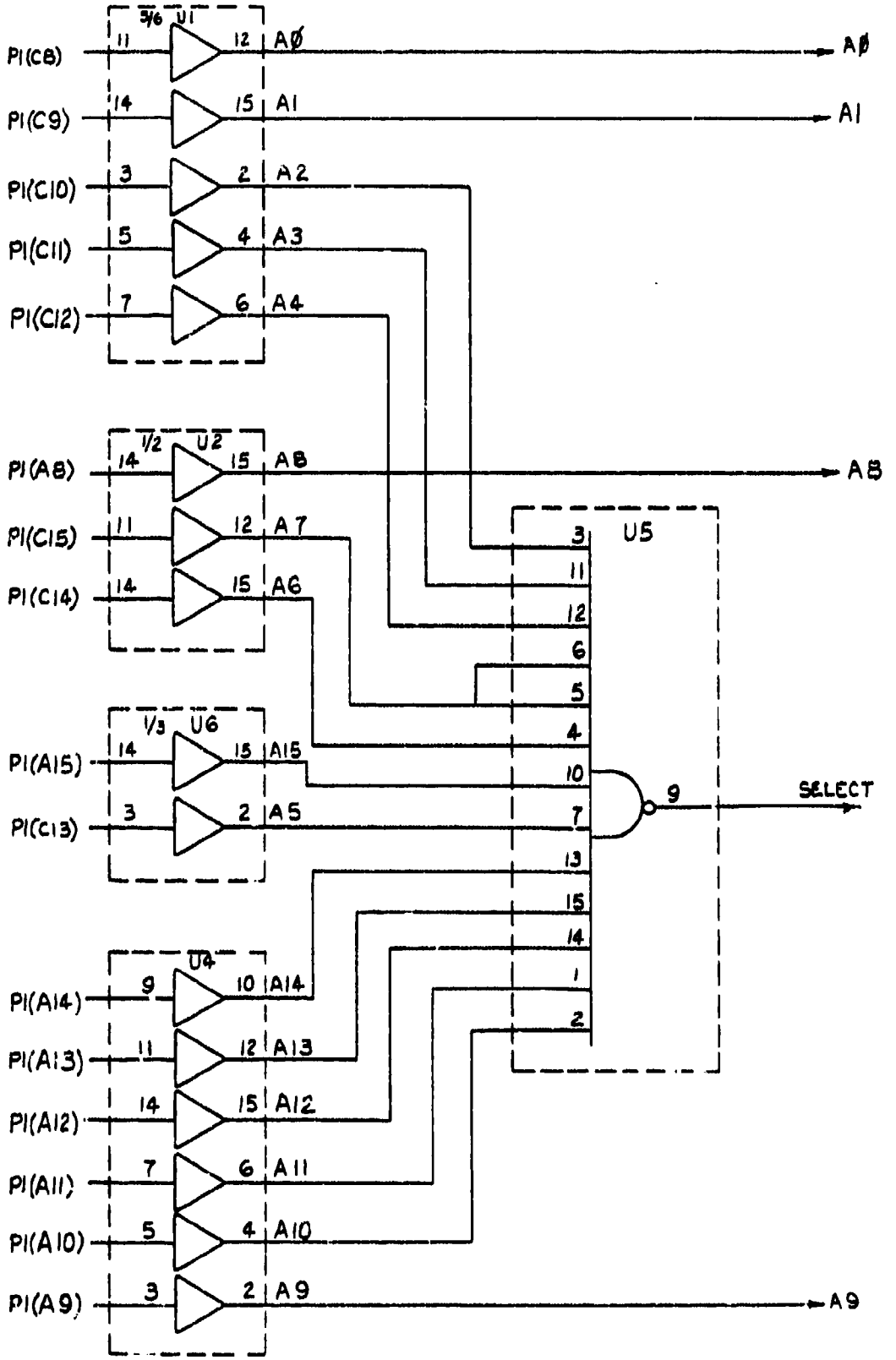


Figure IV-1. Parallel Output Board Address Buffer

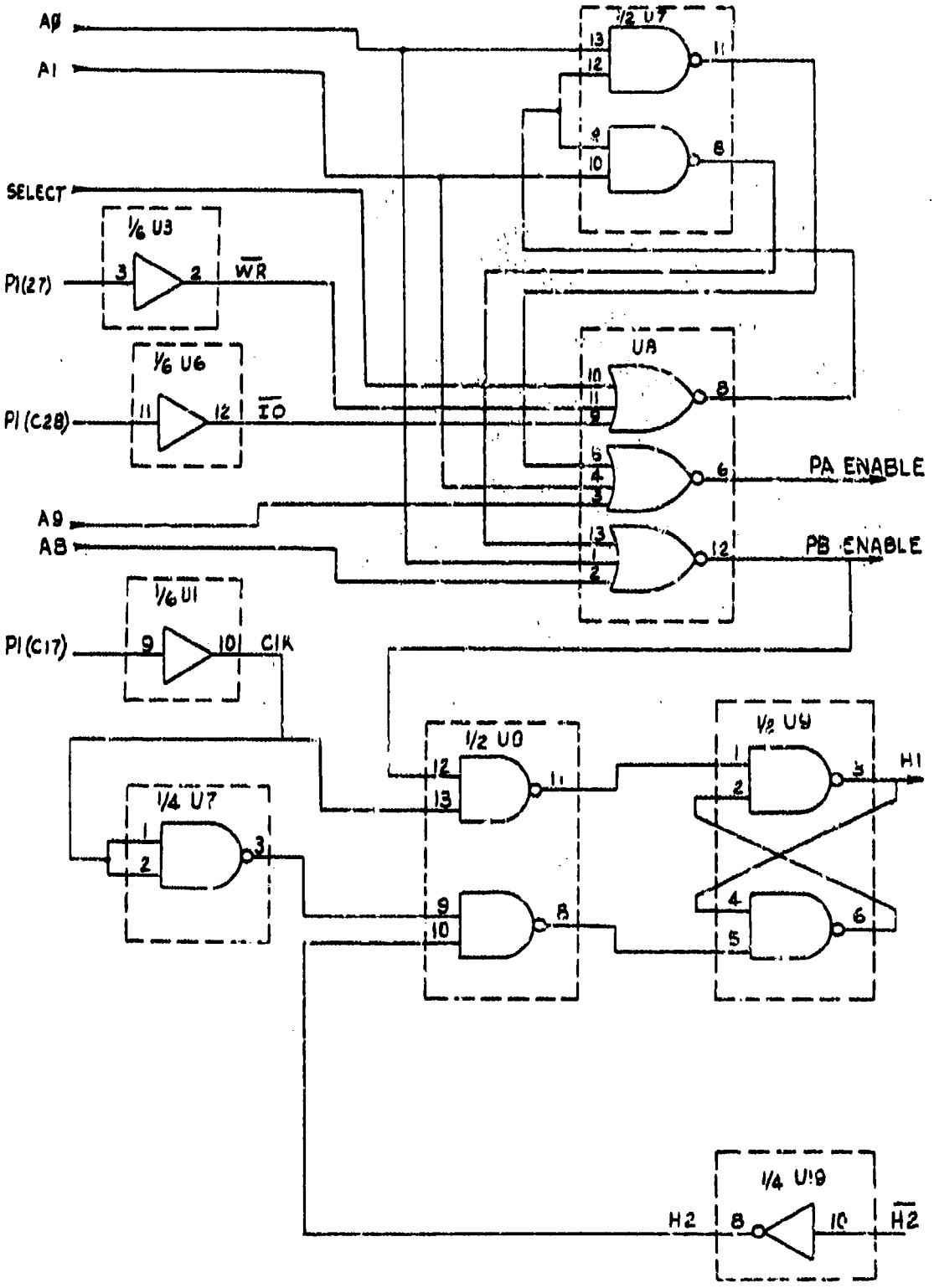


Figure IV-2. Latch Enable and Handshake Logic

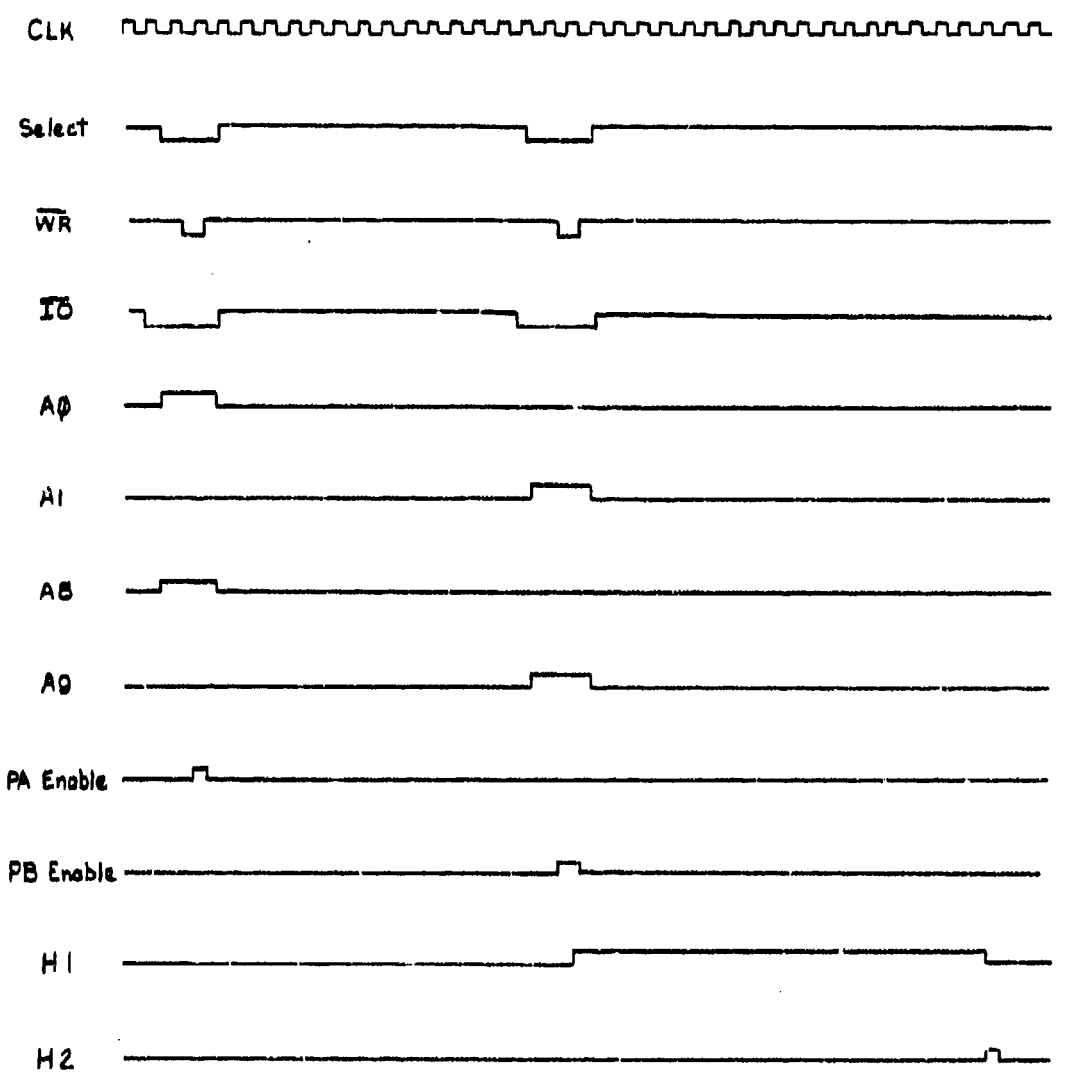


Figure IV-3. Timing Diagram For the Board Select and Handshaking Circuitry

U12, a 74374 hex-latch, as shown in figure IV-4.

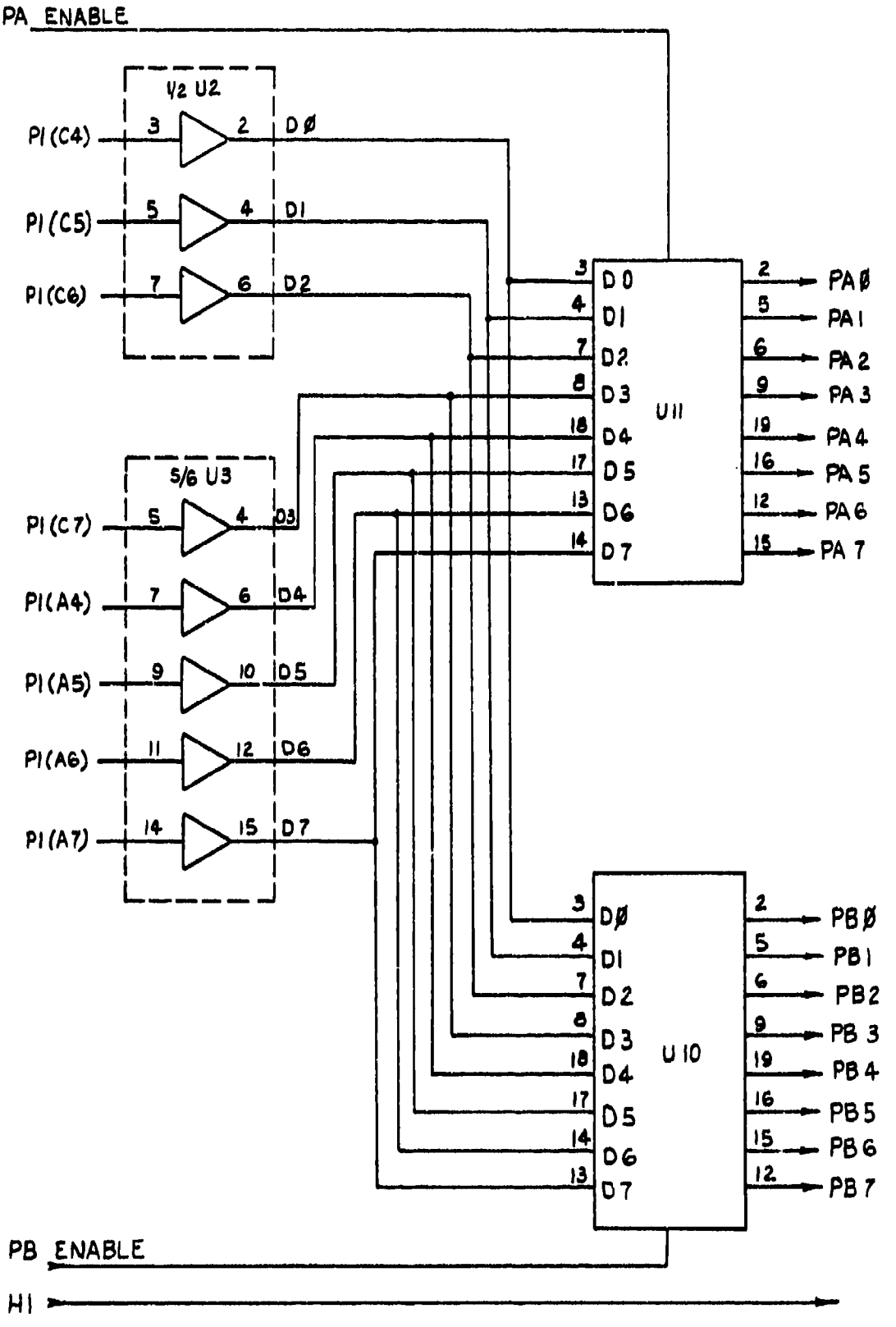
Handshaking Circuitry. The parallel output board has hardwired two-way handshaking circuitry as shown in the lower portion of figure IV-2. The latch-B enable signal initiates the handshaking sequence when the CIM microcomputer cycle is high by driving the output of the cross-coupled nand latch which is wired on U9 to a logic high level.

The output of the cross-coupled latch is H1, the valid data ready handshaking signal. This signal tells the remote signal-processing receiver circuitry that new valid data is available on the data lines passing through the sliprings.

When the remote signal processing receiver circuitry receives an H1 signal, a nine microsecond delay is initiated by the circuitry on the receiver test board shown in figure IV-9. After this delay, the received data is latched and a data accepted handshake signal, H2, is transmitted to the parallel output board. This H2 signal resets the H1 output from the cross-coupled latch.

The timing diagram for the handshaking circuitry is shown in figure IV-3.

Parity Generating Circuitry. The parallel output board generates a parity bit to allow the remote signal processing receiver circuitry to detect any single bit errors in the data which is transmitted through the slip rings. This parity check bit is generated by two cascaded 74280 parity generators, U12 and U14, shown in figure IV-5. These parity



FigureIV-4. Data Buffering and Latching Circuitry

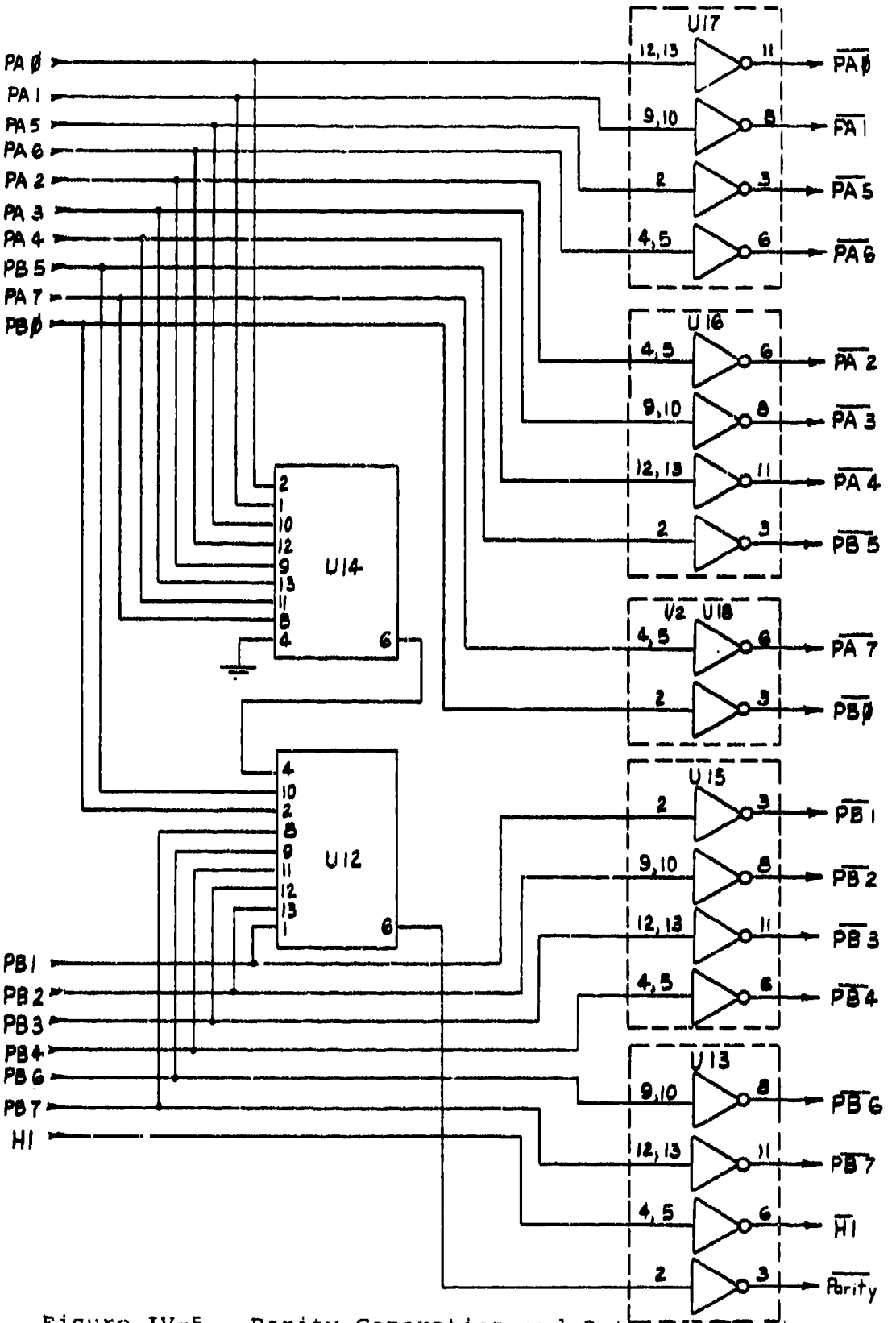


Figure IV-5. Parity Generation and Output Buffering

generators get their input data by tapping the output of the latches, U10 and U11, in figure IV-4.

Output and Input Buffers. Transmission of data and control signals through the slip-rings and transmission lines is done at RS-232 voltage levels of +15 volts and -15 volts, corresponding respectively to a logic low and a logic high.

The slip-rings were tested using a 30 volt peak-to-peak square wave. The distortion to the signal passing through the slip-rings was less than one volt. The RS-232 voltage levels will help to minimize data errors which might be caused by noise and attenuation if the slip-rings are degraded by wear or contamination.

The buffering is accomplished by 1488 Line Drivers and 1489 Line Receivers on boards at both ends of the slipring data channel. The 18 output lines from the parallel output board carrying the 16 data bits, H1, and the parity check bit are buffered from TTL voltage levels to RS-232 voltage levels by the 1488 Line Drivers, which are U13, U15, U16, U17, and U18 in figure IV-5. The H2 input line is buffered from RS-232 voltage levels to TTL voltage levels by the 1489 Line Receiver, U19, shown in figure IV-2.

Receiver Test Board Circuit Description

A receiver test board was constructed to test the operation of the parallel output board and the sliprings. This board was necessary because the Masscomp computer,

which is to be used as a remotely located signal processor and controller, has not arrived at this time. The receiver test board will also be useful for troublesnooting applications if data transmission problems between the parallel output board and signal processing hardware arise in the future.

Logic diagrams of the receiver test board circuitry are shown in figures IV-6, 7, and 8. A shematic diagram of the handshake delay circuitry, referenced in figure IV-7, is shown in figure IV-9. An assembly drawing which shows the integrated circuit pack placements, an integrated circuit listing, and a signal line interconnection listing are in Appendix C. A listing of a computer program to test the parallel output board with the receiver test board is provided in Appendix D.

Input and Output Buffers. The receiver test board has 1489 Line Receivers and a 1488 Line Driver which are matched to the 1488s and 1489 on the parallel output board. The 18 input lines from the parallel output board are buffered from RS-232 voltage levels to TTL voltage levels by the 1489 Line Receivers shown in figures IV-6 and IV-7 as U1, U2, U3, U4, and U12. The H2 output signal to the parallel output board is buffered from TTL voltage levels to RS-232 voltage levels by the 1488 Line Driver shown as U17 in figure IV-7.

Parity Check Circuitry. The parity check circuitry, shown as U5, U8, and U6 in figures IV-6 and IV-7, prevents single bit errors from occurring in the 16 bits of data

being received from the parallel output board. U5 and U8, the cascaded 74280 parity generators tap the 16 input data lines to compute the parity bit for the received data. An exclusive-or function is performed on the test parity bit and the parity bit received from the parallel output board in U6. The result of this exclusive-or function will be a logic level one only when the two parity bits match. As we can see in figure IV-7, the latching circuitry of the receiver test board will not be enabled unless the two parity bits match.

Latch Control and Handshake Logic. A logic diagram of the latch control and handshake circuitry on the receiver test board is shown in figure IV-7. The H1 handshake signal received from the parallel output board is delayed by approximately nine microseconds by the delay circuitry shown in detail in figure IV-9. This delay provides the data being transmitted from the parallel output board with a settling time to prevent transient responses from causing errors.

The heart of the delay circuitry is an LM556 timer configured as a gated astable multivibrator. The discrete integration network causes the output of the delay circuitry to be delayed from the input by nine microseconds. This provides the received data with a settling period.

The output of the delay circuitry triggers the latch enable circuitry and the H2 handshake signal generating circuitry on U10. As the data is latched by the parallel

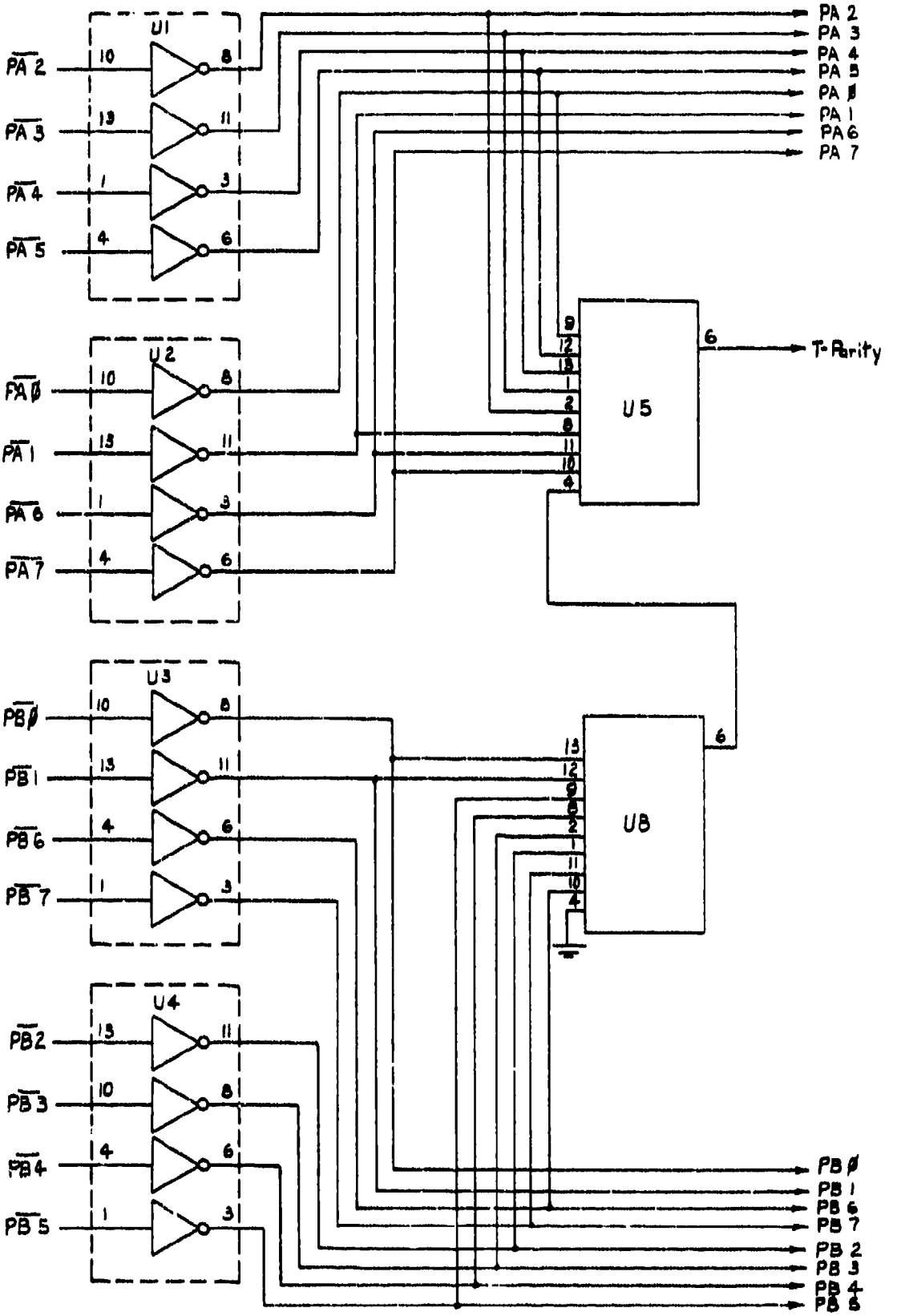


Figure IV-6. Test Board Input Buffering

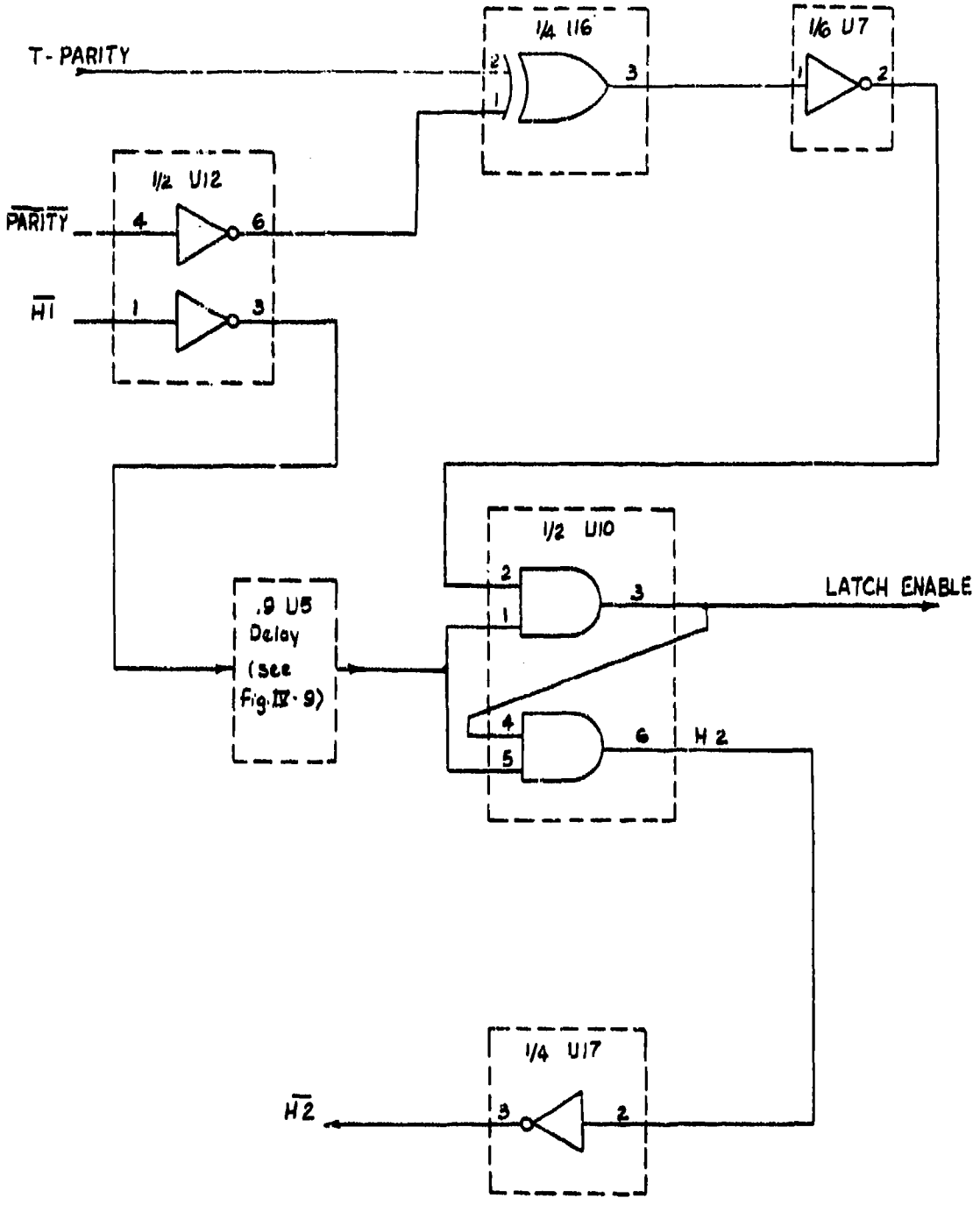


Figure IV-7. Test Board Latch Control Logic

output board and immediately available at the inputs of the receiver test board latches, and the parity bit from the parallel output board is calculated at the output of the parallel output board; the parity bit match or mismatch will be at the input of U10 well before the delayed H1 signal causes the data to be latched in. Therefore, the latch enable signal is generated on the high transition of the delayed H1 pulse if and only if the two independently generated parity bits for the data match. The latch enable signal will cause H2 to transition to a logic high state; this will cause the parallel output board to reset the H1 handshake signal, which will disenable the latch enable signal on the receiver test board.

The handshake circuitry is the only logic on the receiver test board which should require redesign for application in the actual signal processing receiver circuitry. This design cannot be done at this time due to the fact that the Masscomp computer and documentation have not arrived yet; therefore, the handshake protocol cannot be fully defined at this time.

Latch and Display Circuitry. The latch and display circuitry on the receiver test board is shown in figure IV-8. The single latch enable signal from the circuitry in figure IV-7 simultaneously latches the 16 data bits into the 74373 latches, U9 and U11. As there is no signal processing circuitry presently connected, the outputs of the latches are connected to four hex displays: U13, U14, U15, and U16.

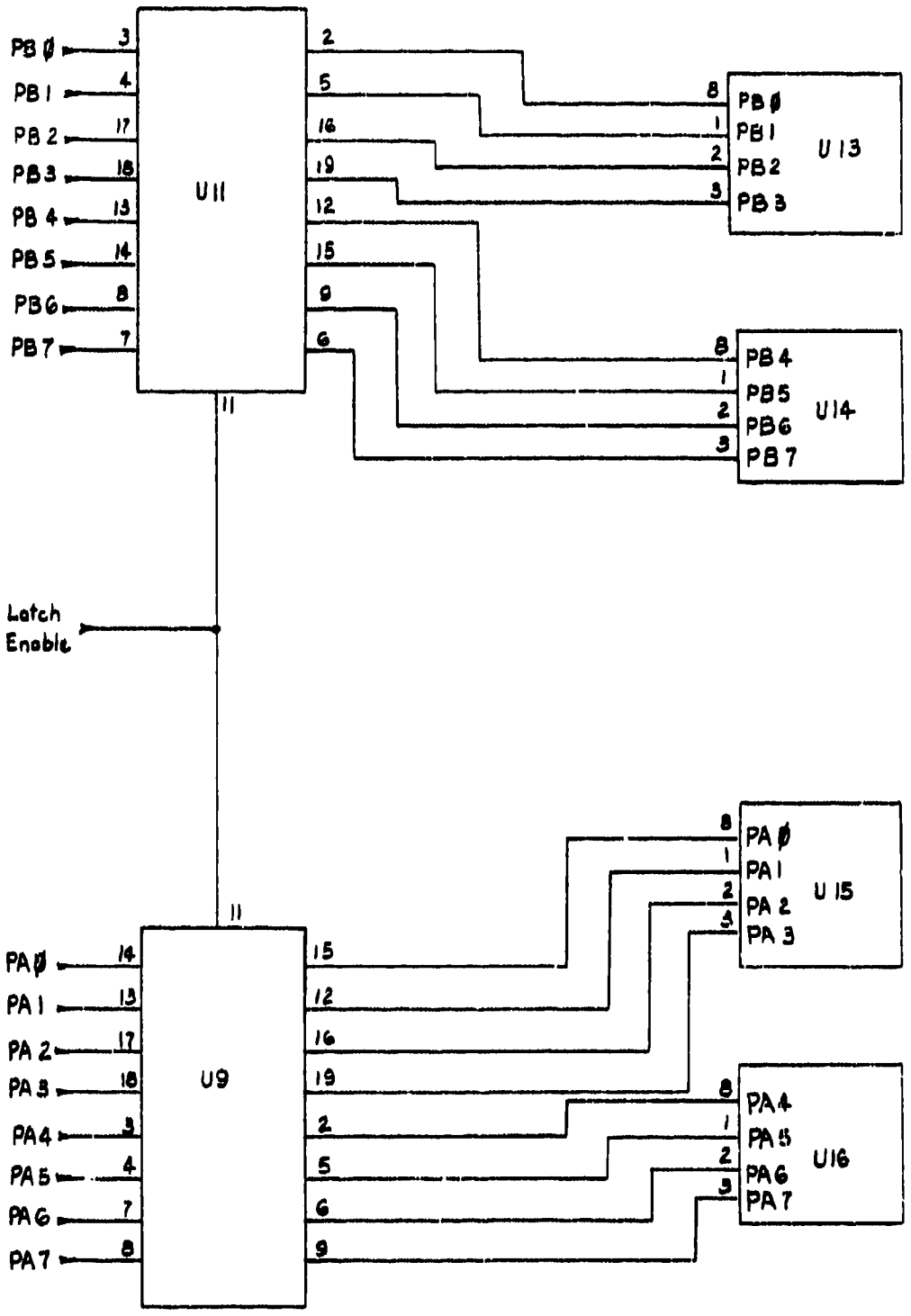


Figure IV-8. Test Board Latch and Display Circuitry

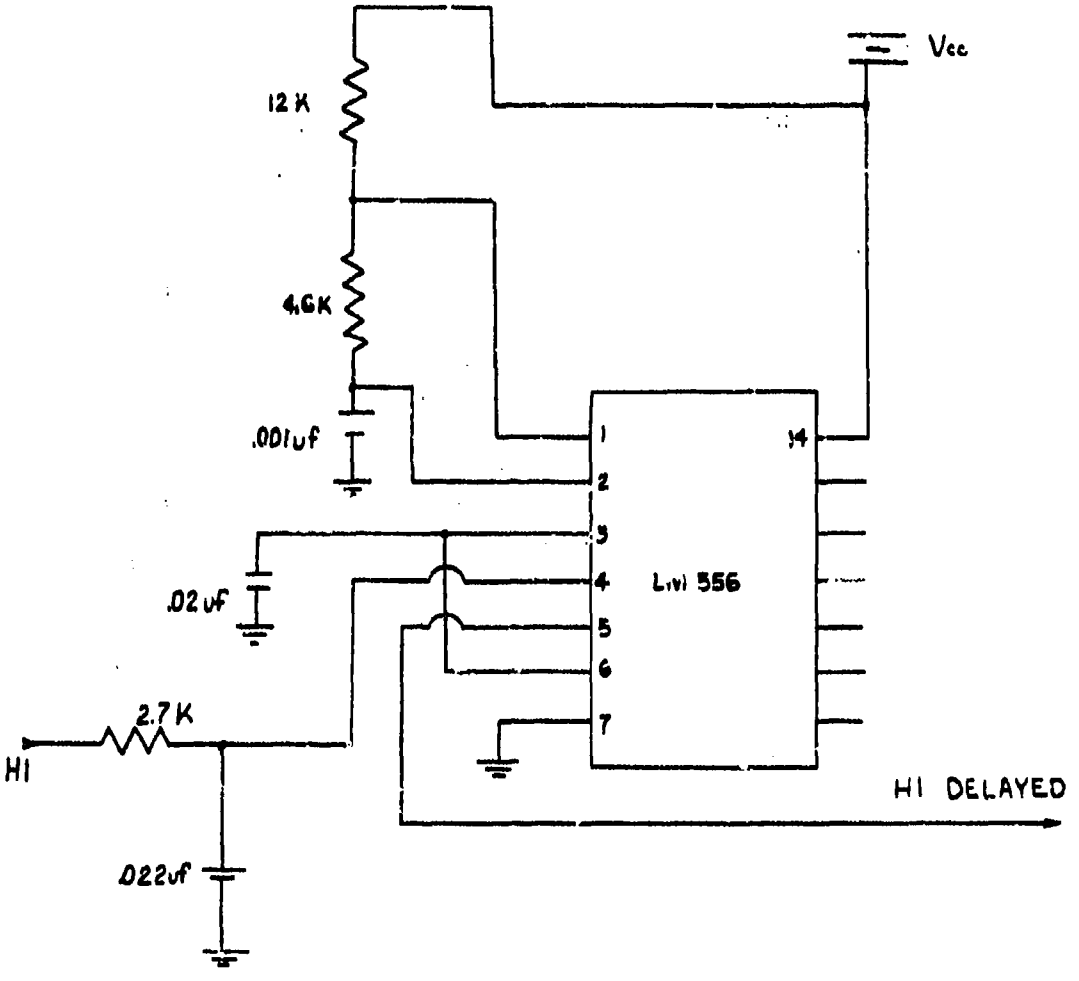


Figure IV-9. Test Board Delay Circuitry

These displays allow an experimenter to view a value which the onboard computer has been programmed to output to the parallel output board. On the actual signal processing receiver board, the lines going to the hex displays will be the data inputs into the Masscomp computer.

V Recommendations For Future Study

The equipment built in this thesis effort should provide a good foundation for a follow-on thesis which would be primarily a data collection, as well as an algorithm developing effort.

After the remote signal processing computer, a Masscomp 500, is installed, this facility will be among the most powerful tools in the world for collecting data on coriolis induced motion sickness. We now provide some suggestions as to how the computer facilities might be used; what equipment modifications might be considered; what basic development work is required; and how future experiments might progress.

Having both the onboard CIM microcomputer and offboard Masscomp computer will provide a distributed computing system, allowing an experimenter great flexibility in choosing his sampling and data processing algorithms. The onboard microcomputer has been installed to handle all data sampling and analog-to-digital conversion in a manner that is determined by an experimenter's computer program, such as the one in Appendix E. The Masscomp computer is envisioned as performing three tasks, each task having a specific processor dedicated to it: one processor handling input from the onboard CIM microcomputer as well as data storage; one central processor performing real-time and off-line data analysis; and one processor providing graphics displays to assist an experimenter who is training a subject.

Equipment Modifications to be Considered

While the present pneumograph transducers work well, they are somewhat bulky. Attention might be given to a possible redesign of the pneumograph transducers during a follow-on thesis effort. The concept of using variable capacitors as the sending element has proven to be very worthwhile; but, the size of the transducers might be reduced to eliminate the possible alignment conflict with other electrodes on the subject's torso.

One possible alternative is to develop a variable coaxial capacitor. This would eliminate much of the mechanical linkage currently needed, reducing the size of the transducers.

Basic Development and Future Experiment Progression

Although a device has been installed to allow a subject to provide his input to an experimenter, no scale has been developed to train the subject in how to provide this input. We believe that this scale must be developed in conjunction with the software development to insure compatability.

A future experimenter should devise a scale that will be computationally efficient for the signal processing equipment to process and allow a subject to be readily trained in computing what he believes his degree of motion sickness to be. The most universally accepted scale for determining the degree of motion sickness being experienced is the Coriolis Sickness Susceptibility Index (CSSI) which

was devised by Dr. Ashton Graybiel (Ref 9). The CSSI should provide a good starting point for designing a self-rating scale.

An input for the experimenter to provide his subjective input as to the state of the subject at a given time should also be installed. We envision this input being generated under the same scale as the subject's input.

Future Experiment Progression. The next set of experiments should concentrate on collecting data by monitoring subjects in the chair. This will help develop a data base which does not exist in a digital format. It is likely that the rate of change in certain physiological parameters, when normalized by a subject's responses when he is not under stress, will have a much higher correlation with his state of motion sickness than would the absolute value of these parameters. Past results at NASA have shown that physiological measurements and their relationships to states of motion sickness vary from individual to individual, as well as from one time to another. Therefore, it would likely be most profitable if data is repeatedly taken under different, but very well documented, conditions. Circadian rhythm is one variable that might be investigated in relationship to the changes in an individual's responses from time to time.

Much of the analysis to be done is promising material for basic neuro-psychological and biophysical research; but, analysis with spectral, temporal, and statistical analysis

techniques may unlock hidden secrets about the causes and cures of motion sickness. The equipment that has been developed will provide the most sophisticated capability for collecting needed data that we know to exist in the world.

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Appendix A

Functional Description And Key Component Parts Layout

This appendix functionally describes each key component of the designed physiological monitoring circuits and outlines its physical location on the applicable circuit card. The designed circuits include the electrocardiograph/electrogastograph, photo-plethysmograph, and pneumograph. A brief circuit description is included. Operating and alignment instructions are provided in appendix B.

Electrocardiogram(ECG)/Electrogastogram(EGG). The electrocardiograph circuit card is shown in figure A-1 and the electrogastograph circuit card is shown in figure A-2. The key components layout is shown in figure A-3 for both the ECG and EGG circuit boards since the circuit layouts and functional operations are identical. The circuits are designed to acquire extremely weak biophysical signals from the subject, filter out the wideband background noise, and amplify the signal to a usable level.

The first stage in the circuit is a buffer amplifier (U1). This amplifier is a chopper stabilized amplifier chosen for its extremely high input impedance, high gain, and stability characteristics. This stage provides the necessary isolation for the safety of the subject. The gain of this stage has been fixed at twenty dB.

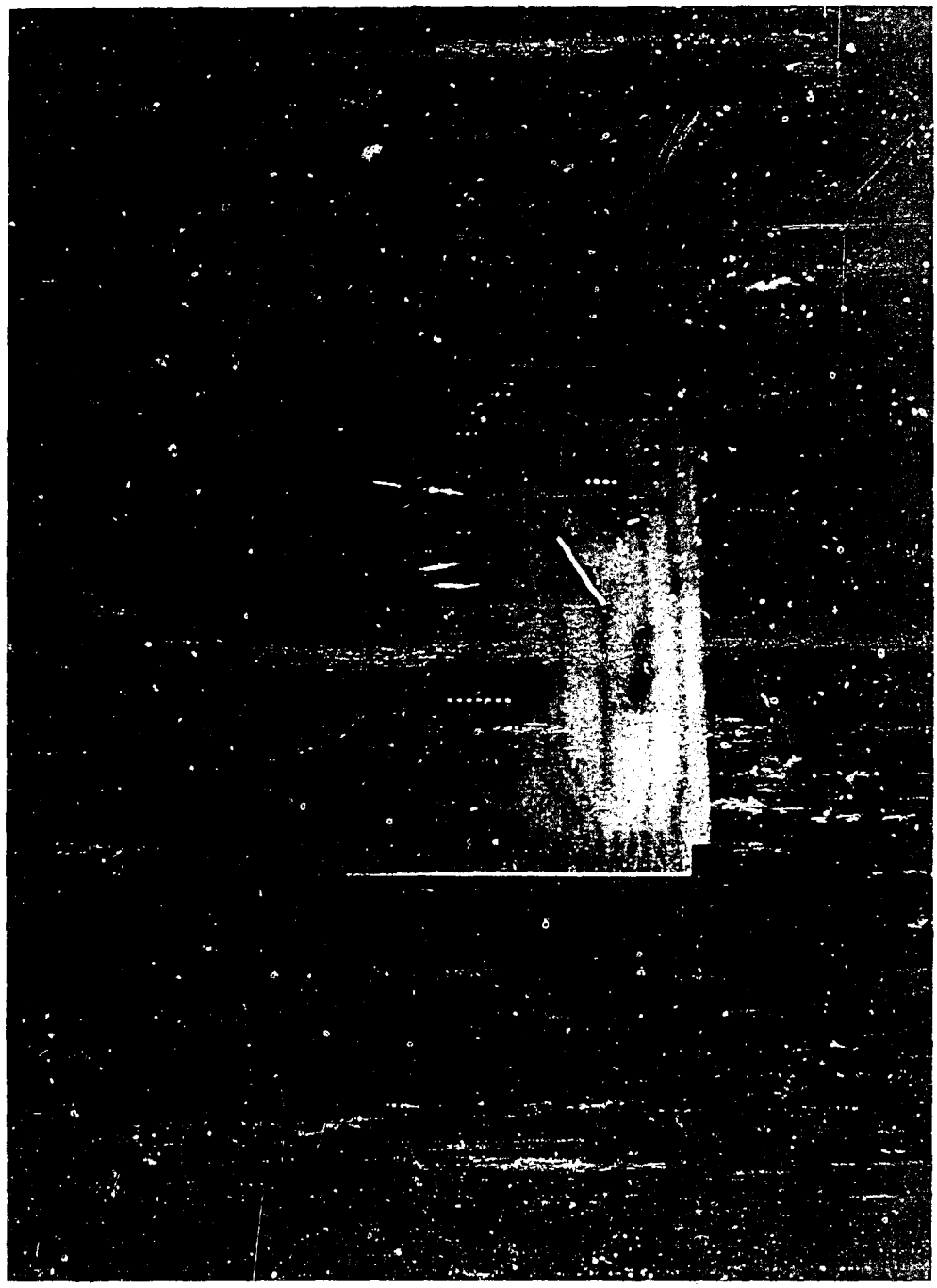


Figure A-1. ECG Circuit Card

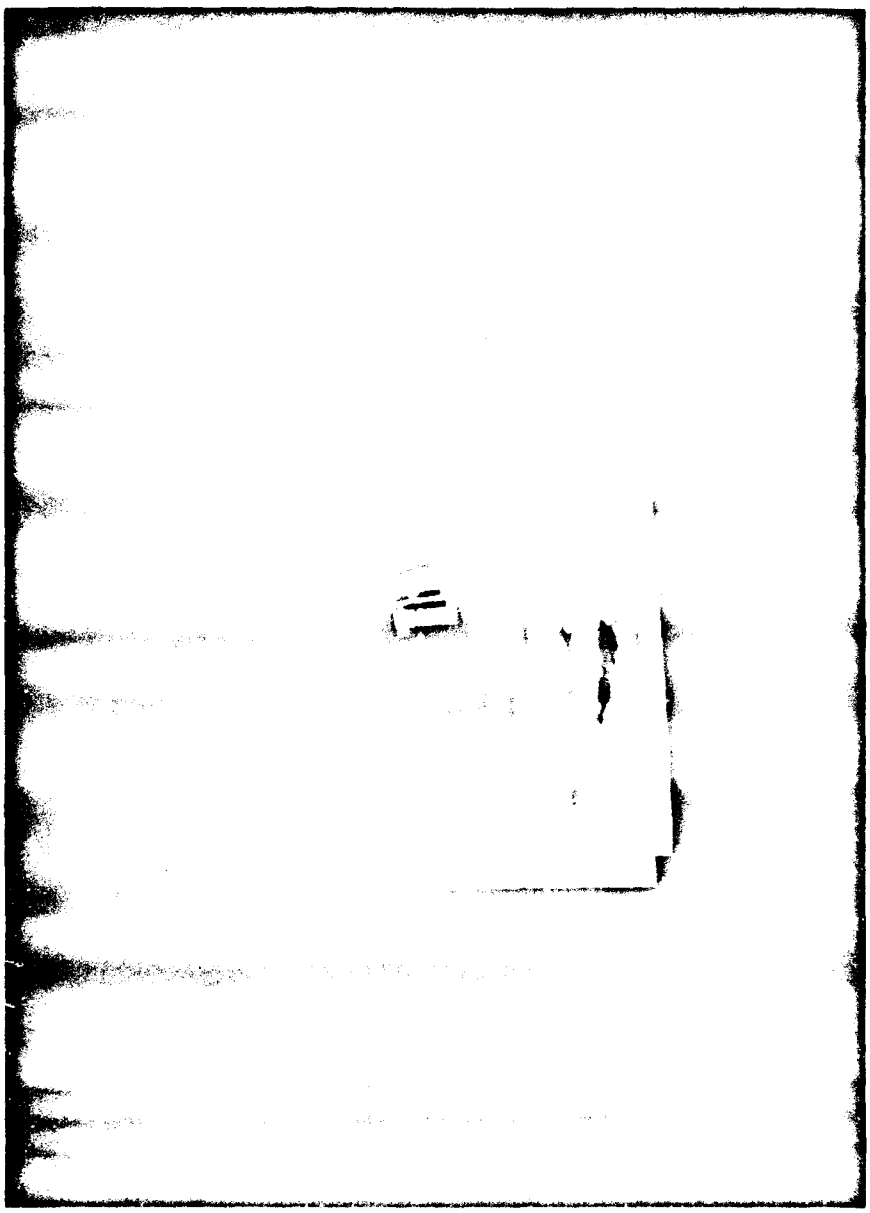


Figure A-2. EGG Circuit Card

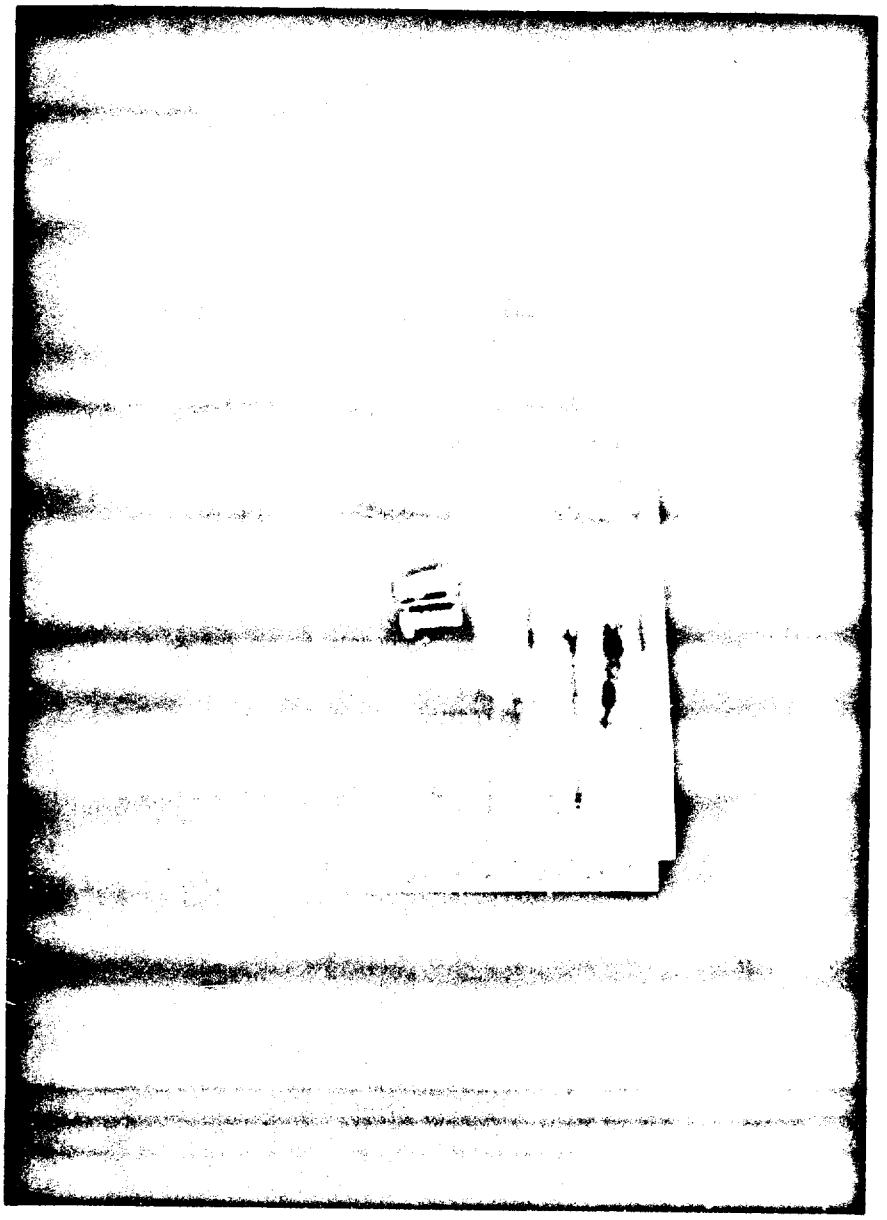
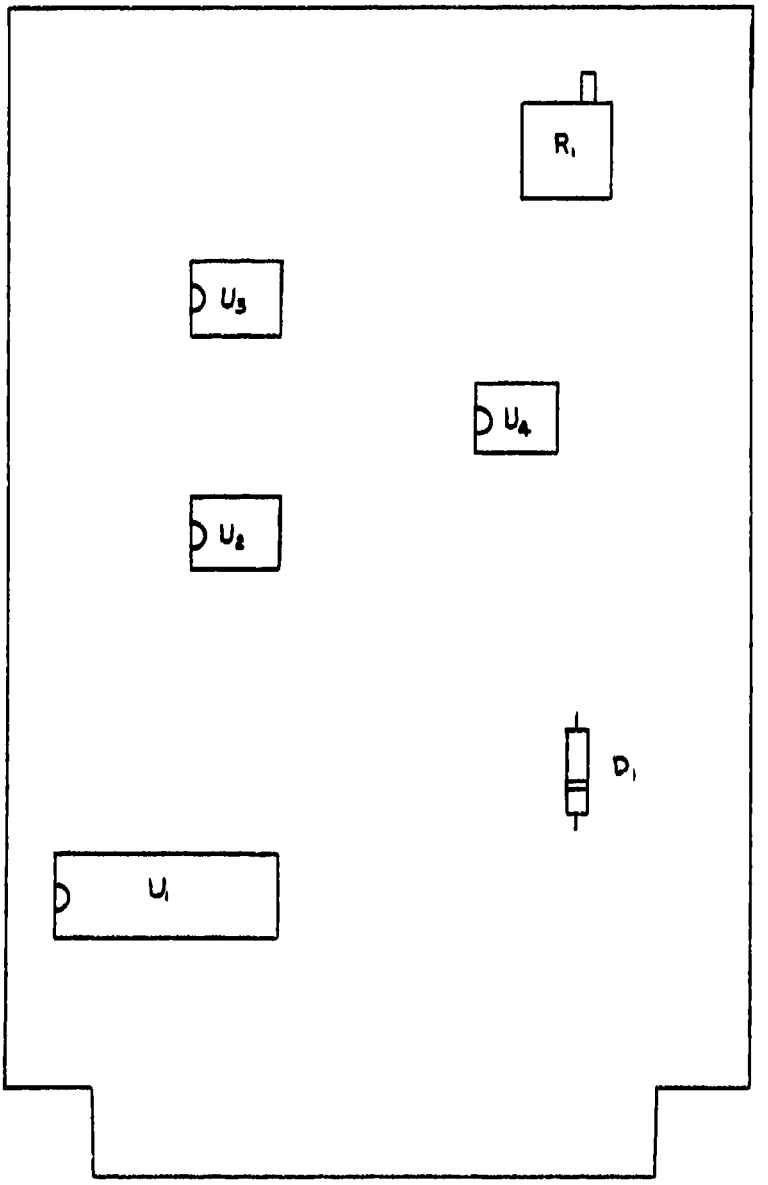


Figure A-2. EGG Circuit Card



U_1 - Intersil ICL 7650 CPD

U_2, U_3, U_4 - National Semiconductor

D_1 - IN 750A

R_1 - 50KΩ, 10 Turn

Figure A-3. ECG/EGG Key Component Layout

The output of the first stage is fed into a second order high-pass filter (U2). The low frequency cutoff of this filter is .05 hertz for the ECG circuit and .006 hertz for the EGG circuit. This filter removes any DC component from the buffer amplifier output but allows the low frequency components to pass.

A third order low-pass filter (U3) follows the output of the high-pass filter. The high frequency cutoff of the filter is 20 hertz for the ECG circuit and .12 hertz for the EGG circuit. These values were chosen to maximize the signal to noise ratio and preserve the necessary signal components.

The last stage is a adjustable gain amplifier (U4) with a level shift (D1) in the output. The gain can be adjusted over a range of fourteen to twenty-two dB. The level shift restores a 4.7 volt DC offset in order to present the bipolar signal as a unipolar signal. The output of this final stage is connected to the patch panel in the battery compartment.

Photo-Plethysmograph. The photo-plethysmograph circuit card is shown in figure A-4 and the key components layout is shown in figure A-5. The circuit card contains two identical circuits placed symmetrically on the board. The finger photo-plethysmograph will be described; with the identically placed component for the facial blood photo-plethysmograph included in parenthesis. In each case a transducer was constructed to illuminate the skin with a

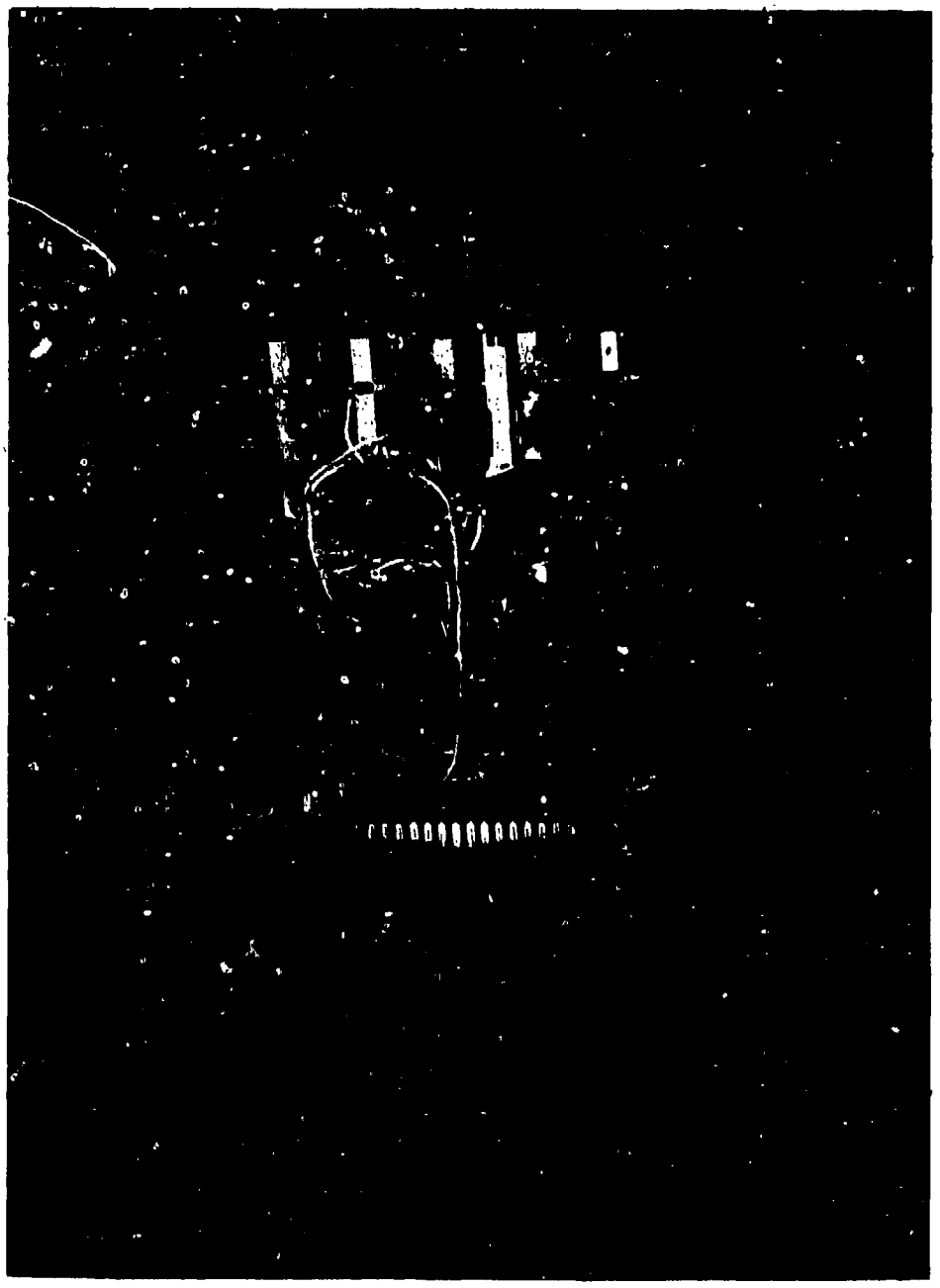
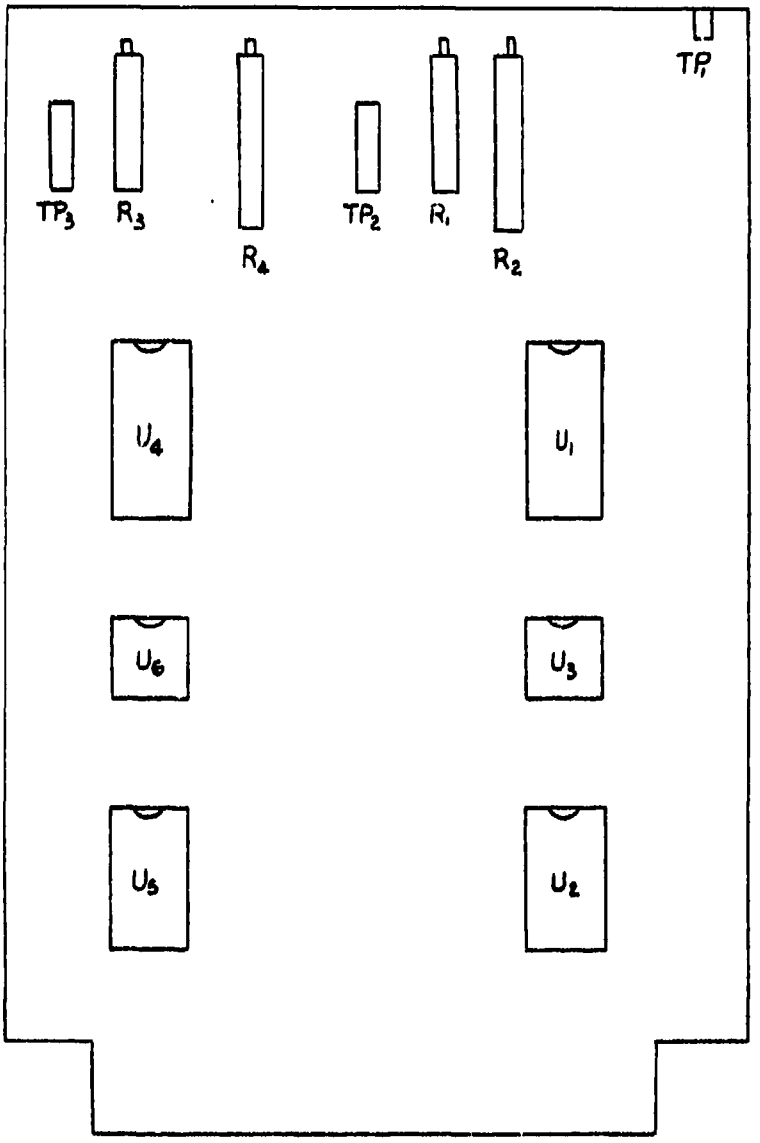


Figure A-4. Photo-plethysmograph Circuit Card



U_1, U_2, U_4, U_5 - National Semiconductor LF 444 A

U_3, U_6 - National Semiconductor LF 356 A

R_1, R_3 - 50K Ω, 10 Turn

R_2, R_4 - 5KΩ, 10 Turn

Figure A-5. Photo-plethysmograph Key Component Layout

narrow beam of low intensity infrared light. The transducer for the finger is designed to receive light which has penetrated the finger. The facial transducer is designed to receive light which is reflected by the interior flesh of the face. In each case, the blood pulse causes a change in the light received by the photo-transistor which is proportional to the blood volume. The transducers are shown in figure III-8 of the text.

The gain of the photo transistor is adjusted by R1 (R3). The output of the transistor is applied to a bandpass filter U1 (U4). U1a and U1b (U4a and U4b) are cascaded third order high-pass filters sourcing cascaded third order low-pass filters, U1c and U1d (U4c and U4d) respectively. The passband of this circuit is .25 - 5 hertz.

The output of this stage is fed into another quad BiFET amplifier. U2a (U5a) is a gain stage which is adjusted by R2 (R4) to set the baseline blood pulse volume prior to experimentation. U2b (U5b) is a second order high-pass filter feeding U2c (U5c), a second order low-pass filter; both having the same overall passband performance as before. A half wave rectifier U2d (U5d), which also stretches the output, follows the output from the filter.

The stretched negative pulse is applied to an integrator U3 (U6) along with the unstretched output of the bandpass filter U2d (U5d). The unstretched pulse actually arrives ahead of the stretched pulse and tends to reset the integrator to a lower level. This allows a more accurate

representation of the blood pulse volume than if the integrator was not reset.

Pneumograph. There were two pneumograph transducers built as shown in figure III-7a of the text; one to measure the expansion of the chest cavity and one to measure the expansion of the abdomen by the diaphram. The pneumograph circuit card is shown in figure A-6 and the key components layout is shown in figure A-7. Each of the circuits are identical and symmetrically arranged on a single circuit card as shown in figure A-7. The circuit for the chest expansion will be described and the corresponding components for the abdomen expansion measuring circuit will be shown in parenthesis.

The transducer is a variable capacitor which is mechanically linked to the expansion of the chest (abdomen). This variable capacitor sets the frequency of an oscillator U1a (U1c) which is applied to a frequency-to-voltage converter U2 (U3). The output of this device, a varying DC level about a three volt DC baseline, is fed into a level shifting and amplifier circuit U1b (U1d). The variable resistor R1 (R3) allows the baseline to be shifted to zero volts, corresponding to a fully compressed transducer. This adjustment can be used to compensate for changes in component values due to age or replacement. Variable resistor R2 (R4) is used to adjust the output for a ten volt level for a fully expanded transducer.

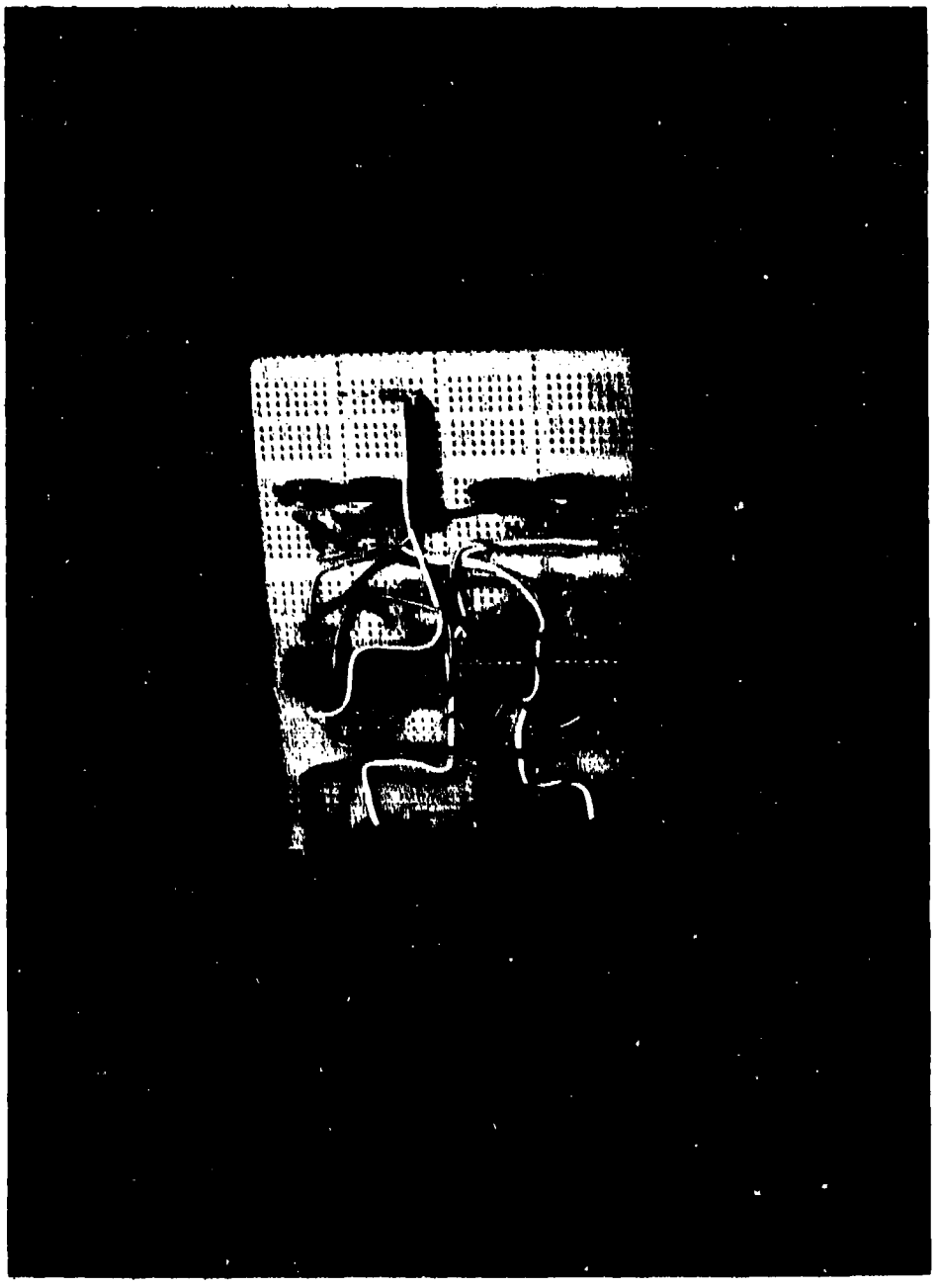
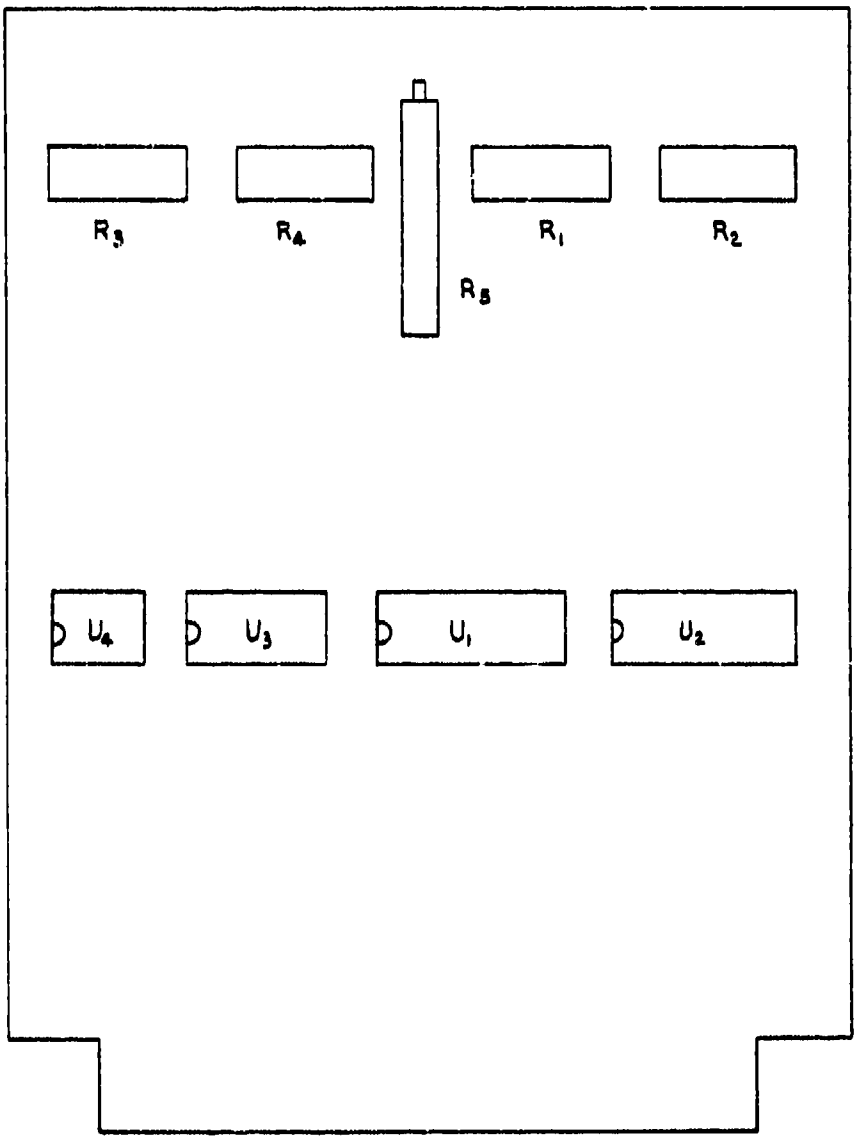


Figure A-6. Pneumograph Circuit Card



U_1	- National Semiconductor	LF 444A
U_2, U_3	- National Semiconductor	LM 2907 N
U_4	- National Semiconductor	LF 356 A

R_1, R_2, R_3, R_4 - 2K Ω
R_5 - 10K Ω, 10 Turn

Figure A-7. Pneumograph Key Component Layout

Appendix B

Equipment Operating Procedures

This appendix describes the operating procedures for the biophysical collection system. These procedures were developed for the equipment configuration described in Appendix A. The operating procedures for the multiaxis simulator are found in simulator's operations manual and will not be included in this study.

Electrode/Transducer Preparation. The first step in preparing for data collection is to properly attach the electrodes and transducers. It is important to prepare the subject's skin, following the manufacturer's instructions, before attaching the disposable ECG and EGG electrodes. This will result in a low contact impedance of typically twenty kilohms.

The pneumograph transducers are placed on the subject only after the ECG and EGG electrodes have been attached. Final strap adjustment can be accomplished after the subject has been seated in the simulator. The transducers should be adjusted for full compression with exhale, with expansion starting at the begining of inhale. This will insure accurate respiration data.

The only alignments required for the photo-plethysmographs is for subject comfort. The facial transducer should be attached with the electrical cord

directed towards the subject's ear.

Equipment Turn-On. The equipment should be turned on only after the subject is seated in the simulator and all transducers and electrodes have been connected to the junction box. Experience has shown that a two minute warm up period is needed to allow all of the initial transient responses of the system to decay. The baseline responses of the signals can then be checked to insure that usable unsaturated data is being collected. Any signal irregularities found after sufficient warm up time has elapsed should be corrected by following the alignment procedures included in this appendix.

Caution

Safety precautions should be observed by assisting the subject into and out of the simulator. This is especially important after the experiment since the subject's sense of balance is likely to be quite unstable.

Alignment Procedures

Electrocardiogram/Electrogastogram. This alignment should be performed only after the electrodes are installed and the system has sufficient time to stabilize (typically two minutes).

1. Disconnect the appropriate ECG/EGG output lead from the junction panel in the battery compartment.
2. Connect the output lead to a BNC/banana

connector adapter and the other end of the adapter to a digital voltmeter.

3. Adjust the gain control resistor (R1) on the appropriate circuit card fully counterclockwise for maximum gain. Reduce the gain until all of the excursions are between zero and ten volts.

4. Disconnect the test adapter and reconnect the output lead.

Photo-Plethysmograph.

1. Connect the digital voltmeter leads into TP1 and TP2 (finger transducer) or TP3 (facial transducer).

2. Adjust R1 (TP2) or R3 (TP3) for a eight to nine volt output. This will set the proper gain of the photo transistor.

3. Repeat steps 1 and 2 of the ECG alignment procedures.

4. Adjust R2 (TP2) or R4 (TP3) for a signal level of nine volts. This will establish the gain for the maximum blood pulse volume of the subject.

5. Disconnect the test equipment and reconnect the output lead to the patch panel.

Pneumograph. No alignment is normally necessary except to compensate for component aging or parts replacement.

1. Repeat steps 1 and 2 of the ECG alignment

procedures.

2. Adjust R1 for zero volts with the chest transducer compressed (R3 for the abdomen transducer) and R2 for ten volts with the chest transducer expanded (R4 for the abdomen transducer).

3. Disconnect the test equipment and reconnect the output lead to the patch panel.

Appendix C

Parallel Output Board IC Listing

Component	Device Type	Description
U1	CD4010	Hex Buffer (Non-Inverting)
U2	CD4010	Hex Buffer (Non-Inverting)
U3	CD4010	Hex Buffer (Non-Inverting)
U4	CD4010	Hex Buffer (Non-Inverting)
U5	SN74133	13-Input Nand Gate
U6	CD4010	Hex Buffer (Non-Inverting)
U7	SN7400	Quad 2-Input Nand Gate
U8	SN7427	Triple 3-Input Nor Gate
U9	SN7400	Quad 2-Input Nand Gate
U10	SN74374	Octal D-Type Flip-Flops
U11	SN74374	Octal D-Type Flip-Flops
U12	SN74280	9-Bit Parity Generator/Checker
U13	DS1488	Quad Line Driver
U14	SN74280	9-Bit Parity Generator/Checker
U15	DS1488	Quad Line Driver
U16	DS1488	Quad Line Driver
U17	DS1488	Quad Line Driver
U18	DS1488	Quad Line Driver
U19	DS1489	Quad Line Receiver

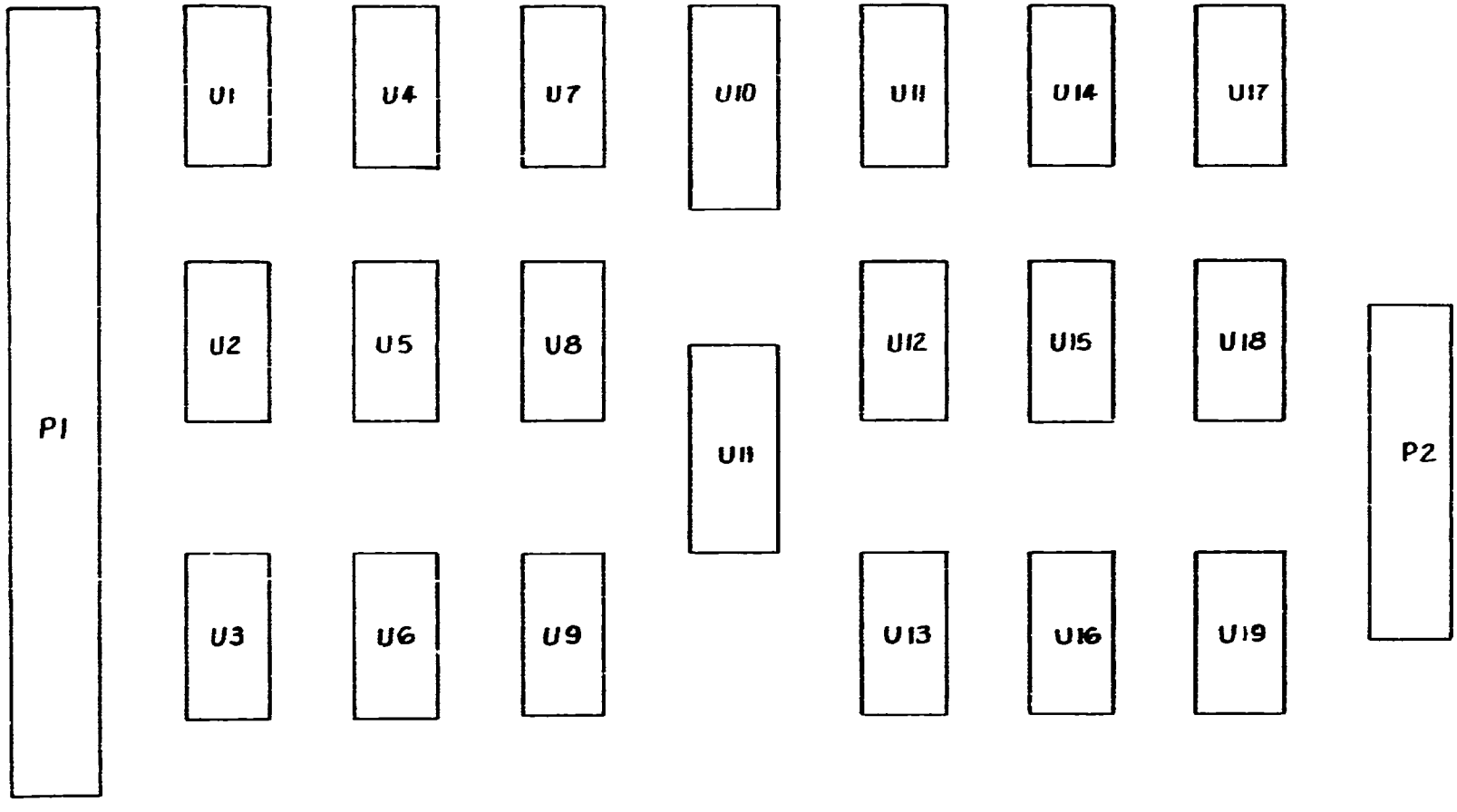


Figure C-1. Assembly Drawing of Parallel Output Board (wire-wrap side up)

Parallel Output Board Intercomponent Wiring List

Component	Pin #	Destination	Signal Name
U1	1	+5v Buss	+5v
	2	U5-3	A2
	3	P1-C10	A2
	4	U5-11	A3
	5	P1-C11	A3
	6	U5-12	A4
	7	P1-C12	A4
	8	Gnd Buss	Gnd
	9	P1-C17	Clk
	10	U7-1,U7-2,U9-13	Clk
	11	P1-C8	A0
	12	U7-13,U8-1	A0
	13	N/C	
	14	P1-C9	A1
	15	U7-10,U8-4	A1
	16	+5v Buss	+5v
U2	1	+5v Buss	+5v
	2	U10-3,U11-3	D0
	3	P1-C4	D0
	4	U10-4,U11-4	D1
	5	P1-C5	D1
	6	U10-7,U11-7	D2
	7	P1-C6	D2

Component	Pin #	Destination	Signal Name
	8	Gnd Buss	Gnd
	9	P1-A8	A8
	10	U8-2	A8
	11	P1-C15	A7
	12	U5-5,U5-6	A7
	13	N/C	
	14	P1-C14	A6
	15	U5-4	A6
	16	+5v Buss	+5v
U3	1	+5v Buss	+5v
	2	U8-11	WR
	3	P1-C27	WR
	4	U10-8,U11-8	D3
	5	P1-C7	D3
	6	U10-18,U11-18	D4
	7	P1-A4	D4
	8	Gnd Buss	Gnd
	9	P1-A5	D5
	10	U10-17,U11-17	D5
	11	P1-A6	D6
	12	U10-14,U11-13	D6
	13	N/C	
	14	P1-A7	D7
	15	U10-13,U11-14	D7
	16	+5v Buss	+5v

Component	Pin #	Destination	Signal Name
U4	1	+5v Buss	+5v
	2	U8-4	A9
	3	P1-A9	A9
	4	U5-2	A10
	5	P1-A10	A10
	6	U5-1	A11
	7	P1-A11	A11
	8	Gnd Buss	Gnd
	9	P1-A14	A14
	10	U5-13	A14
	11	P1-A13	A13
	12	U5-15	A13
	13	N/C	
	14	P1-A12	A12
	15	U5-14	A12
	16	+5v Buss	+5v
U5	1	U4-6	A11
	2	U4-4	A10
	3	U1-2	A2
	4	U2-15	A6
	5	U2-12,U5-6	A7
	6	U2-12,U5-5	A7
	7	U6-2	A5
	8	Gnd Buss	Gnd
	9	U8-10	select

Component	Pin #	Destination	Signal Name
	10	U6-15	A15
	11	U1-4	A3
	12	U1-6	A4
	13	U4-10	A12
	14	U4-15	A14
	15	U4-12	A13
	16	+5v Buss	+5v
U6	1	+5v Buss	+5v
	2	U5-7	A5
	3	P1-C13	A5
	4	N/C	
	5	N/C	
	6	N/C	
	7	N/C	
	8	Gnd Buss	Gnd
	9	N/C	
	10	N/C	
	11	N/C	
	12	P1-C28	IO
	13	U8-9	IO
	14	P1-A15	A15
	15	U5-10	A15
	16	+5v Buss	+5v
U7	1	U1-10,U7-2,U9-13	clk

Component	Pin #	Destination	Signal Name
	2	U1-10,U7-1,U9-13	clk
	3	U9-9	clk
	4	N/C	
	5	N/C	
	6	N/C	
	7	Gnd Buss	Gnd
	8	U8-13	
	9	U8-8,U7-12	
	10	U1-15,U8-4	A1
	11	U8-5	
	12	U7-9,U8-8	
	13	U1-12,U8-1	A0
	14	+5v Buss	+5v
U8	1	U1-12,U7-13	A0
	2	U1-2,U8-3	A2
	3	U1-2,U8-2	A2
	4	U7-10,U1-15	A1
	5	U7-11	
	6	U11-11	
PA Enable			
	7	Gnd Buss	Gnd
	8	U7-9,U7-12	
	9	Gnd Buss	
	10	U5-9	Select
	11	U3-2	

Component	Pin #	Destination	Signal Name
	12	U9-12,U10-11	PB Enable
	13	U7-8	
	14	+5v Buss	+5v
U9	1	U9-11	
	2	U9-6	
	3	U9-4,U13-4,U13-5	H1
	4	U9-3,U13-4,U13-5	H1
	5	U9-8	
	6	U9-2	
	7	Gnd Buss	Gnd
	8	U9-5	
	9	U7-3	clk
	10	U19-8	H2
	11	U9-1	
	12	U8-12,U10-11	PB Enable
	13	U7-2,U7-1,U1-10	clk
	14	+5v Buss	+5v
U10	1	Gnd Buss	
	2	U12-2,U18-2	PB0
	3	U11-3,U2-2	D0
	4	U11-4,U2-4	D1
	5	U12-1,U15-2	PB1
	6	U12-13,U15-9,U15-10	PB2
	7	U11-7,U2-6	D2

Component	Pin #	Destination	Signal Name
	8	U3-4,U11-8	D3
	9	U12-12,U15-13,U15-12	PB3
	10	Gnd Buss	Gnd
	11	U8-12,U9-12	PB Enable
	12	U12-8,U13-12U13-13	PB7
	13	U3-15,U11-14	D7
	14	U3-12,U11-13	D6
	15	U12-9,U13-10,U13-9	PB6
	16	U12-10,U16-2	PB5
	17	U3-10,U11-17	D5
	18	U3-6,U11-18	D4
	19	U12-11,U15-4,U15-5	PB4
	20	+5v Buss	+5V
U11	1	Gnd Buss	
	2	U14-2,U17-12,U17-3	PA0
	3	U2-2,U10-3	D0
	4	U2-4,U10-4	D1
	5	U14-1,U17-9,U17-10	PA1
	6	U14-13,U16-4,U16-5	PA2
	7	U2-6,U10-7	D2
	8	U3-4,U10-8	D3
	9	U14-12,U16-10,U16-9	PA3
	10	Gnd Buss	Gnd
	11	U8-6	PA Enable
	12	U14-9,U17-4,U17-5	PA6

Component	Pin #	Destination	Signal Name
	13	U3-12,U10-14	D6
	14	U3-15,U10-13	D7
	15	U14-8,U18-4,U18-5	PA7
	16	U14-10,U17-2	PA5
	17	U3-10,U10-17	D5
	18	U3-6,U11-18	D4
	19	U14-11,U16-12,U16-13	PA4
	20	+5v Buss	+5v
U12	1	U10-5,U15-2	PB1
	2	U10-2,U18-2	PB0
	3	N/C	
	4	U14-6	
	5	N/C	
	6	U13-2	Parity
	7	Gnd Buss	Gnd
	8	U10-12,U13-13,U13-12	PB7
	9	U10-15,U13-9,U13-10	PB6
	10	U10-16,U16-2	PB5
	11	U10-19,U15-4,U15-5	PB4
	12	U10-9,U15-13,U15-12	PB3
	13	U10-6,U15-10,U15-9	PB2
	14	+5v Buss	+5v
U-13	1	-15v Buss	-15v
	2	U12-6	Parity

Component	Pin #	Destination	Signal Name
	3	P2-12	Parity
	4	U13-5,U9-3,U9-4	H1
	5	U13-4,U9-3,U9-4	H1
	6	P2-11	H1
	7	Gnd Buss	Gnd
	8	P2-9	PB6
	9	U13-10,U12-9,U10-15	PB6
	10	U13-9,U12-9,U10-15	PB6
	11	P2-10	PB7
	12	U12-8,U13-13,U10-12	PB7
	13	U13-12,U12-8U10-12	PB7
	14	+15v Buss	+15v
U14	1	U11-5,U17-9,U17-10	PA1
	2	U11-2,U17-12,U17-13	PA0
	3	N/C	
	4	Gnd Buss	
	5	N/C	
	6	U12-4	
	7	Gnd Buss	Gnd
	8	U11-15,U18-4,U18-5	PA7
	9	U11-12,U17-4,U17-5	PA6
	10	U11-16,U17-2	PA5
	11	U11-19,U16-12,U16-13	PA4
	12	U11-9,U16-10,U16-9	PA3
	13	U11-6,U16-4,U16-5	PA2

Component	Pin #	Destination	Signal Name
	14	+5v Buss	+5v
U15	1	-15v Buss	-15v
	2	U12-1,U10-5	PB1
	3	P2-4	PB1
	4	U12-11,U10-19,U15-5	PB4
	5	U12-11,U10-19,U15-4	PB4
	6	P2-7	PB4
	7	Gnd Buss	Gnd
	8	P2-5	PB2
	9	U15-10,U12-13,U10-6	PB2
	10	U15-9,U12-13,U10-6	PB2
	11	P2-6	PB3
	12	U12-12,U10-9,U15-13	PB3
	13	U12-12,U15-12,U10-9	PB3
	14	+15v Buss	+5v
U16	1	-15v Buss	-15v
	2	U12-10,U10-16	PB5
	3	P2-8	PB5
	4	U14-13,U16-5,U11-6	PA2
	5	U14-13,U16-4,U11-6	PA2
	6	P2-18	PA2
	7	Gnd Buss	Gnd
	8	P2-19	PA3
	9	U14-12,U16-10,U11-9	PA3

Component	Pin #	Destination	Signal Name
	10	U14-12,U16-9,U11-9	PA3
	11	P2-20	PA4
	12	U14-11,U16-13,U11-19	PA4
	13	U14-11,U16-12,U11-19	PA4
	14	+15v Buss	+15v
U17	1	-15v Buss	-15v
	2	U14-10,U11-16	PA5
	3	P2-15	PA5
	4	U14-9,U17-5,U11-12	PA6
	5	U14-9,U17-4,U11-12	PA6
	6	P2-22	PA6
	7	Gnd Buss	Gnd
	8	P2-17	PA1
	9	U14-1,U17-10,U11-5	PA1
	10	U14-1,U17-9,U11-5	PA1
	11	P2-16	PA0
	12	U14-2,U17-13,U11-2	PA0
	13	U14-2,U17-12,U11-2	PA0
	14	+15v Buss	+15v
U18	1	-15v Buss	-15v
	2	U12-2,U10-2	PB0
	3	P2-3	PB0
	4	U14-8,U18-5,U11-15	PA7
	5	U14-8,U18-4,U11-15	PA7

Component	Pin #	Destination	Signal Name
	6	P2-23	PA7
	7	Gnd Buss	Gnd
	8	N/C	
	9	N/C	
	10	N/C	
	11	N/C	
	12	N/C	
	13	N/C	
	14	+15v Buss	+15v
U19	1	N/C	
	2	N/C	
	3	N/C	
	4	N/C	
	5	N/C	
	6	N/C	
	7	Gnd Buss	Gnd
	8	U9-10	H2
	9	N/C	
	10	P2-24	H2
	11	N/C	
	12	N/C	
	13	N/C	
	14	+5v Buss	+5v

Receiver Test Board IC Listing

Component	Device Type	Description
U1	DS1489	Quad Line Receiver
U2	DS1489	Quad Line Receiver
U3	DS1489	Quad Line Receiver
U4	DS1489	Quad Line Receiver
U5	SN74280	9-Bit Parity Generator/Checker
U6	SN7486	Quad 2-Input Exclusive-Or Gates
U7	SN7404	Hex Inverters
U8	SN74280	9-Bit Parity Generator/Checker
U9	SN74373	Octal D-Type Latches
U10	SN7408	Quad 2-Input And Gates
U11	SN74373	Octal D-Type Latches
U12	DS1489	Quad Line Receiver
U13	HP5082-7340	Hexidecimal Indicator
U14	HP5082-7340	Hexidecimal Indicator
U15	HP5082-7340	Hexidecimal Indicator
U16	HP5082-7340	Hexidecimal Indicator
U17	DS1488	Quad Line Driver
U18	LM556	Dual Timer

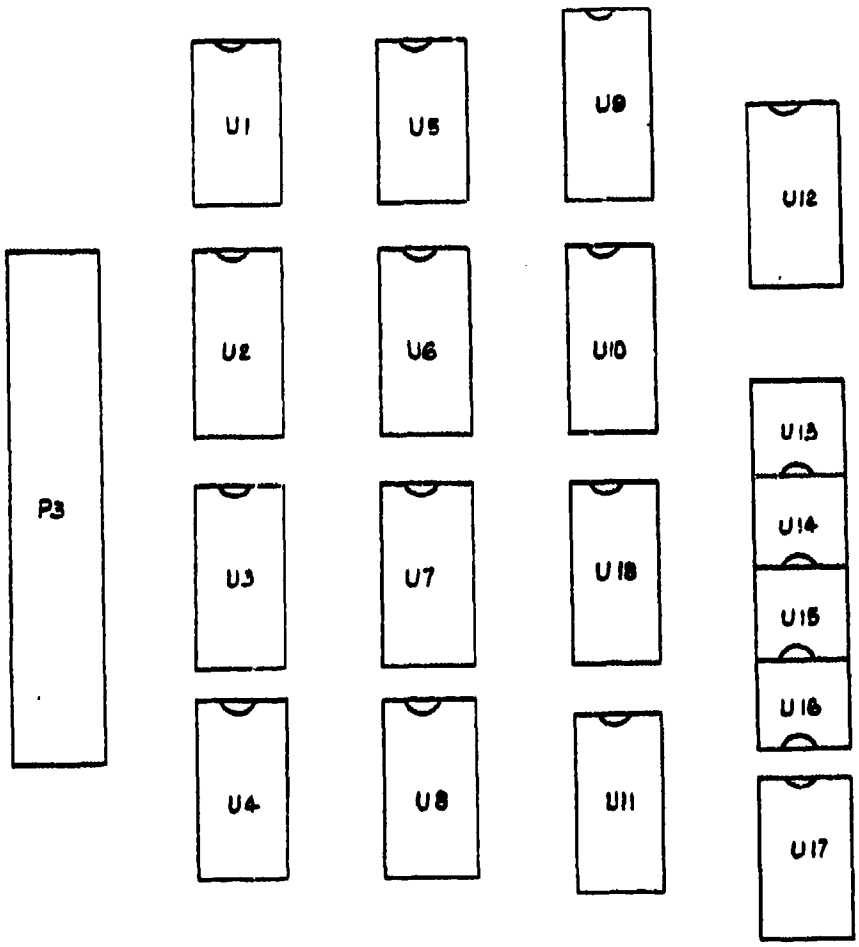


Figure C-2. Receiver Test Board Assembly Drawing

(wire-wrap side view)

Receiver Test Board Intercomponent Wiring List

Component	Pin #	Destination	Signal Name
U1	1	P3-20	PA4
	2	N/C	
	3	U5-13,U9-3	PA4
	4	P3-21	PA5
	5	N/C	
	6	U5-12,U9-4	PA5
	7	Gnd Buss	Gnd
	8	U5-2,U9-17	PA2
	9	N/C	
	10	P3-18	PA2
	11	U5-1,U9-18	PA3
	12	N/C	
	13	P3-19	PA3
	14	+5v Buss	+5v
U2	1	P3-22	PA6
	2	N/C	
	3	U5-11,U9-7	PA6
	4	P3-23	PA7
	5	N/C	
	6	U5-10,U9-8	PA7
	7	Gnd Buss	Gnd
	8	U5-9,U9-14	PA0
	9	N/C	

Component	Pin #	Destination	Signal Name
	10	P3-16	PA0
	11	U5-8,U9-13	PA1
	12	N/C	
	13	P3-17	PA1
	14	+5v Buss	+5v
U3	1	P3-10	PB7
	2	N/C	
	3	U8-11,U11-7	PB7
	4	P3-9	PB6
	5	N/C	
	6	U8-10,U11-8	PB6
	7	Gnd Buss	Gnd
	8	U8-13,U11-3	PB0
	9	N/C	
	10	P3-3	PB0
	11	U8-12,U11-4	PB1
	12	N/C	
	13	P3-4	PB1
	14	+5v Buss	+5v
U4	1	P3-8	PB5
	2	N/C	
	3	U8-9,U11-14	PB5
	4	P3-7	PB4

Component	Pin #	Destination	Signal Name
	5	N/C	
	6	U8-8,U11-13	PB4
	7	Gnd Buss	Gnd
	8	U8-2,U11-18	PB3
	9	N/C	
	10	P3-6	PB3
	11	U8-1,U11-17	PB2
	12	N/C	
	13	P3-5	PB2
	14	+5v Buss	+5v
U5	1	U1-11,U9-18	PA3
	2	U1-8,U9-17	PA2
	3	N/C	
	4	U8-6	
	5	N/C	
	6	U6-2	T-Parity
	7	Gnd Buss	Gnd
	8	U2-11,U9-13	PA1
	9	U2-8,U9-14	PA0
	10	U2-6,U9-8	PA7
	11	U2-3,U9-7	PA6
	12	U1-6,U9-4	PA5
	13	U1-3,U9-3	PA4
	14	+5v Buss	+5v

Component	Pin #	Destination	Signal Name
U6	1	U12-6	Parity
	2	U5-6	T-Parity
	3	U7-1	
	4	N/C	
	5	N/C	
	6	N/C	
	7	Gnd Buss	Gnd
	8	N/C	
	9	N/C	
	10	N/C	
	11	N/C	
	12	N/C	
	13	N/C	
	14	+5v Buss	+5v
U7	1	U6-3	
	2	U10-2	
	3	N/C	
	4	N/C	
	5	N/C	
	6	N/C	
	7	Gnd Buss	Gnd
	8	N/C	
	9	N/C	
	10	N/C	
	11	N/C	

Component	Pin #	Destination	Signal Name
	12	N/C	
	13	N/C	
	14	+5v Buss	+5v
U8	1	U4-11,U11-17	PB2
	2	U4-8,U11-18	PB3
	3	N/C	
	4	Gnd Buss	
	5	N/C	
	6	U5-4	
	7	Gnd Buss	Gnd
	8	U4-6,U11-13	PB4
	9	U4-3,U11-14	PB5
	10	U3-6,U11-8	PB6
	11	U3-3,U11-7	PB7
	12	U3-11,U11-4	PB1
	13	U3-8,U11-3	PB0
	14	+5v Buss	+5v
U9	1	Gnd Buss	
	2	U15-8	PA4
	3	U5-13,U1-3	PA4
	4	U5-12,U1-6	PA5
	5	U15-1	PA5
	6	U15-2	PA6
	7	U5-11,U2-3	PA6

Component	Pin #	Destination	Signal Name
	8	U5-10,U2-6	PA7
	9	U15-3	PA7
	10	Gnd Buss	Gnd
	11	U10-5,U10-4,U11-11	Latch Enable
	12	U16-1	PA1
	13	U5-8,U2-11	PA1
	14	U5-9,U2-8	PA0
	15	U16-8	PA0
	16	U16-2	PA2
	17	U5-2,U1-8	PA2
	18	U5-1,U1-11	PA3
	19	U16-3	PA3
	20	+5v Buss	+5v
U10	1	U10-5,U18-5	H1 delayed
	2	U7-2	
	3	U9-11,U11-11,U10-4	Latch Enable
	4	U10-3,U9-11,U11-11	Latch Enable
	5	U10-1,U18-5	H1 delayed
	6	U17-2	H2
	7	Gnd Buss	Gnd
	8	N/C	
	9	N/C	
	10	N/C	
	11	N/C	
	12	N/C	

Component	Pin #	Destination	Signal Name
	13	N/C	
	14	+5v Buss	+5v
U11	1	Gnd Buss	
	2	U14-8	PB0
	3	U8-13,U3-8	PB0
	4	U8-12,U3-11	PB1
	5	U14-1	PB1
	6	U13-3	PB7
	7	U8-11,U3-3	PB7
	8	U8-10,U3-6	PB6
	9	U13-2	PB6
	10	Gnd Buss	Gnd
	11	U10-3,U10-4,U9-11	Latch Enable
	12	U13-8	PB4
	13	U8-8,U4-6	PB4
	14	U8-9,U4-3	PB5
	15	U13-1	PB5
	16	U14-2	PB2
	17	U8-1,U4-11	PB2
	18	U8-2,U4-8	PB3
	19	U14-3	PB3
	20	+5v Buss	+5v
U12	1	P3-11	H1
	2	N/C	

Component	Pin #	Destination	Signal Name
	3	Delay Input	H1
	4	P3-12	Parity
	5	N/C	
	6	U6-1	Parity
	7	Gnd Buss	Gnd
	8	N/C	
	9	N/C	
	10	N/C	
	11	N/C	
	12	N/C	
	13	N/C	
	14	+5v Buss	+5v
U13	1	U11-15	PB5
	2	U11-9	PB6
	3	U11-6	PB7
	4	Gnd Buss	
	5	Gnd Buss	
	6	Gnd Buss	Gnd
	7	+5v Buss	+5v
	8	U11-12	PB4
U14	1	U11-5	PB1
	2	U11-16	PB2
	3	U11-19	PB3
	4	Gnd Buss	

Component	Pin #	Destination	Signal Name
	5	Gnd Buss	
	6	Gnd Buss	Gnd
	7	+5v Buss	+5v
	8	U11-2	PB0
U15	1	U9-5	PA5
	2	U9-6	PA6
	3	U9-9	PA7
	4	Gnd Buss	
	5	Gnd Buss	
	6	Gnd Buss	Gnd
	7	+5v Buss	+5v
	8	U9-2	PA4
U16	1	U9-12	PA1
	2	U9-16	PA2
	3	U9-19	PA3
	4	Gnd Buss	
	5	Gnd Buss	
	6	Gnd Buss	Gnd
	7	+5v Buss	+5v
	8	U9-15	PA0
U17	1	-15v Buss	-15v
	2	U10-6	H2
	3	P3-24	H2

Component	Pin #	Destination	Signal Name
	4	N/C	
	5	N/C	
	6	N/C	
	7	Gnd Buss	Gnd
	8	N/C	
	9	N/C	
	10	N/C	
	11	N/C	
	12	N/C	
	13	N/C	
	14	+15v Buss	+15v

For U18 wiring see Figure IV-8.

Appendix D

Test Program

```
;     This program allows an experimenter to test the
; parallel output board and the slipring data transmission
; channel by using the receiver test board.  The receiver
; test board can be connected either directly to the
; parallel output board on the chair, or indirectly to the
; parallel output board through the slipring data
; transmission channel.  This will aid troubleshootin
; efforts if problems arise which might be caused by the
; parallel output board or the data transmission channel.

;*************************************************************

;     This program is written in Z-80 assembly language,
; which is fully compatible with the CIM microcomputer
; system, to allow the use of existing equipment at AFIT.
;
                                    .Z80
                                    ASEG
;
; Start program in memory location 8000H
                                    ORG       8000H
;
; Initialize and output 0000 to receiver test board.  Port
; FDH corresponds to the 8 least significant bits being
```

```
; output.  Port FEH corresponds to the 8 most significant
; bits being output.
8000    3E 00                           LD      A,00H
8002    32 F100                         LD      (F100H),A
8005    D3 FD                           OUT     (0FDH),A
8007    D3 FE                           OUT     (0FEH),A
;
; Delay approximately one second.
8009    11 0001                         LD      DE,1
800C    21 DF36             LP1:        LD      HL,0DF36H
800F    ED 52               LP2:        SBC     HL,DE
8011    CA 8017                         JP      Z,LP3
8014    C3 800F                         JP      LP2
8017    00                  LP3:        NOP
;
;*****************************************************************
;
; This point marks the end of the initialization procedure.
; The remainder of this program is a continuous loop which
; will  operate until the CIM microcomputer is reset by the
; manual reset switch located on top of the CIM cardcage.
; The experimenter will be able to check the equipment
; operation by observing the output display of the receiver
; test board, which changes in one second increments as
; follows:  the initial display is 0000; 0101 is next
; displayed; at this point the display begins an endless
; cycle where the most significant byte is first incremented
```

```
; by one, and approximately one second later the least
; significant byte is incremented by one in a continuous
; loop.  Thus, the display will change in the following
; pattern:  0101, 0201, 0202, 0302, ..., FEFE, FFFE, FFFF,
; 00FF, 0000, 0100, 0101, 0201, ....
;
;*************************************************************
;
;
; Increment basic value and display at output of receiver
; test board.  After the initial two values are displayed,
; this section of code will cause the least significant byte
; to be incremented at the output on the receiver test
; board.
8018    3A F100             TS1:    LD      A,(F100H)
801B    C6 01                       ADD     A,1H
801D    32 F100                     LD      (F100H),A
8020    D3 FD                       OUT     (0FDH),A
8022    D3 FE                       OUT     (0FEH),A
;
; Delay approximately one second.
8024    11 0001                     LD      DE,1
8027    21 DF36             LPA1:   LD      HL,0DF36H
802A    ED 52               LPA2:   SBC     HL,DE
802C    CA 8032                     JP      Z,LPA3
802F    C3 802A                     JP      LPA2
8032    00                  LPA3:   NOP
```

```
;
; Increment the most significant byte on the output of the
; receiver test board.
8033    3A F100                     LD      A,(F100H)
8036    D3 FD                       OUT     (OFDH),A
8038    C6 01                       ADD     A,1H
803A    D3 FE                       OUT     (0FEH),A
803C    11 0001                     LD      DE,1
;
; Delay approximately one second.
803F    21 DF36             LPB1:   LD      HL,0DF36H
8042    ED 52               LPB2:   SBC     HL,DE
8044    CA 804A                     JP      Z,LPB3
8047    C3 8042                     JP      LPB2
804A    00                  LPB3:   NOP
;
; Return to beginning of continuous loop.
804B    C3 8018                     JP      TS1
```

Appendix E

Data Collection Software

```
;     This program allows an experimenter to collect
; physiological data with the CIM microcomputer system and
; the physiological monitoring equipment that is installed
; on the chair.  This program samples the output of the
; electrocardiogram (ECG) at a rate of 450 samples per
; second.  The outputs of the other monitoring equipment are
; sampled 30 times per second.
;
;*************************************************************
;*************************************************************
;
;     This program is written in Z-80 assembly language,
; which is fully compatible with the CIM microcomputer
; system, to allow the use of existing equipment at AFIT.
;
                                        .Z80
                                        ASEG
;
; Start program in memory location 9000H.
                                        org       9000H
;
;    The remainder of this program, until location 90EE, is
; an endless loop that samples the outputs of the monitoring
; equipments by calling the subroutine DSAMP.  Each call to
```

```
; DSAMP causes the CIM computer system analog to digital
; converter to sample the ECG and another physiological
; monitoring equipment which is specified in memory location
; F100H.  When the sampled values are output to the parallel
; output board, a header which specifies the channel
; which was sampled is affixed to the most significant byte
; of the digital value; this header is generated from data
; which is stored in memory location F102H before calling
; DSAMP.  The data in location F102H is a shifted version of
; the data in location F100H; but, has all ones in the
; positions of the four least significant bits.
;     Note that the repetetive structure of the program is
; designed to maintain an equal time interval between
; the sampling of a specific channel.  This timing is
; necessary to allow signal processing techniques to be
; used on the data that is collected.
;*****************************************************************
;
; Sample subjects absolute temperature with Autogen 60.
9000    3E 01                SAMP1:  LD      A,1H
9002    32 F100                      LD      (0F100H),A
9005    3E 1F                        LD      A,1FH
9007    32 F102                      LD      (0F102H),A
900A    CD 90F0                      CALL    DSAMP
900D    C3 9010                      JP      SAMP2
;
; Sample absolute electromogram (EMG) with Autogen 1100.
```

```
9010    3E 02               SAMP2:  LD      A,2H
9012    32 F100                     LD      (0F100H),A
9015    3E 2F                       LD      A,2FH
9017    32 F102                     LD      (0F102H),A
901A    CD 90F0                     CALL    DSAMP
901D    C3 9020                     JP      SAMP3
;
; Sample galvanic skin response (GSR) with Autogen 3000.
9020    3E 03               SAMP3:  LD      A,3H
9022    32 F100                     LD      (0F100H),A
9025    3E 3F                       LD      A,3FH
9027    32 F102                     LD      (0F102H),A
902A    CD 90F0                     CALL    DSAMP
902D    C3 9030                     JP      SAMP4
;
; Sample GSR with Autogen 3400.
9030    3E 04               SAMP4:  LD      A,4H
9032    32 F100                     LD      (0F100H),A
9035    3E 4F                       LD      A,4FH
9037    32 F102                     LD      (0F102H),A
903A    CD 90F0                     CALL    DSAMP
903D    C3 9040                     JP      SAMP5
;
; Sample electrogastrogram (EGG) 1.
9040    3E 05               SAMP5:  LD      A,5H
9042    32 F100                     LD      (0F100H),A
9045    3E 5F                       LD      A,5FH
```

```
9047    32 F102                 LD      (0F102H),A
904A    CD 90F0                 CALL    DSAMP
904D    C3 9050                 JP      SAMP6
;
; Sample EGG 2.
9050    3E 06           SAMP6:  LD      A,6H
9052    32 F100                 LD      (0F100H),A
9055    3E 6F                   LD      A,6FH
9057    32 F102                 LD      (0F102H),A
905A    CD 90F0                 CALL    DSAMP
905D    C3 9060                 JP      SAMP7
;
; Sample EGG 3.
9060    3E 07           SAMP7:  LD      A,7H
9062    32 F100                 LD      (0F100H),A
9065    3E 7F                   LD      A,7FH
9067    32 F102                 LD      (0F102H),A
906A    CD 90F0                 CALL    DSAMP
906D    C3 9070                 JP      SAMP8
;
; Sample EGG 4.
9070    3E 08           SAMP8:  LD      A,8H
9072    32 F100                 LD      (0F100H),A
9075    3E 8F                   LD      A,8FH
9077    32 F102                 LD      (0F102H),A
907A    CD 90F0                 CALL    DSAMP
907D    C3 9080                 JP      SAMP9
```

```
;
; Sample EGG 5.
9080    3E 09               SAMP9:  LD      A,9H
9082    32 F100                     LD      (0F100H),A
9085    3E 9F                       LD      A,9FH
9087    32 F102                     LD      (0F102H),A
908A    CD 90F0                     CALL    DSAMP
908D    C3 9090                     JP      SAMPA
;
; Sample EGG 6.
9090    3E 0A               SAMPA:  LD      A,0AH
9092    32 F100                     LD      (0F100H),A
9095    3E AF                       LD      A,0AFH
9097    32 F102                     LD      (0F102H),A
909A    CD 90F0                     CALL    DSAMP
909D    C3 90A0                     JP      SAMPB
;
; Sample blood pulse volume 1 (finger).
90A0    3E 0B               SAMPB:  LD      A,0BH
90A2    32 F100                     LD      (0F100H),A
90A5    3E BF                       LD      A,0BFH
90A7    32 F102                     LD      (0F102H),A
90AA    CD 90F0                     CALL    DSAMP
90AD    C3 90B0                     JP      SAMPC
;
; Sample blood pulse volume 2 (face).
90B0    3E 0C               SAMPC:  LD      A,0CH
```

```
90B2    32 F100                     LD      (0F100H),A
90B5    3E CF                       LD      A,0CFH
90B7    32 F102                     LD      (0F102H),A
90BA    CD 90F0                     CALL    DSAMP
90BD    C3 90C0                     JP      SAMPD
;
; Sample pneumograph 1 (chest breathing).
90C0    3E 0D           SAMPD:      LD      A,0DH
90C2    32 F100                     LD      (0F100H),A
90C5    3E DF                       LD      A,0DFH
90C7    32 F102                     LD      (0F102H),A
90CA    CD 90F0                     CALL    DSAMP
90CD    C3 90D0                     JP      SAMPE
;
; Sample pneumograph 2 (abdominal breathing).
90D0    3E 0E           SAMPE:      LD      A,0EH
90D2    32 F100                     LD      (0F100H),A
90D5    3E EF                       LD      A,0EFH
90D7    32 F102                     LD      (0F102H),A
90DA    CD 90F0                     CALL    DSAMP
90DD    C3 90E0                     JP      SAMPF
;
; Sample subject's input.
90E0    3E 0F           SAMPF:      LD      A,0FH
90E2    32 F100                     LD      (0F100H),A
90E5    3E FF                       LD      A,0FFH
90E7    32 F102                     LD      (0F102H),A
```

```
90EA    CD 90F0                         CALL      DSAMP
90ED    C3 9000                         JP        SAMP1
;
;***************************************************************
;     This subroutine first samples the electrocardiogram
; (ECG) and outputs the 12 bit digital result with a header
; of 0000 to the parallel output board.  It next samples
; the device specified by the number stored in memory
; location F100H and outputs the 12 bit digital result with
; a header identifying the sampled device.  This header is
; generated from data stored in memory location F102H, and
; is actually the same as the number of the sampled device
; stored in location F100H.
;***************************************************************
;
; Clear the A/D converter output ports.
90F0    DB 00                 DSAMP:  IN        A,(00H)
;
;Start the A/D conversion of the ECG.
90F2    3E 80                         LD        A,80H
90F4    D3 03                         OUT       (03H),A
;
; Delay for 0.00103  seconds for spacing between sampling
; times.  If the sampling frequency is changed, this delay
; cannot be reduced beyond 0.00004 seconds; if it is, the
; data from the A/D converter will not be valid.
90F6    11 0001                       LD        DE,1H
```

```
90F9    21 002D             LP1:    LD      HL,02DH
90FC    ED 52               LP2:    SBC     HL,DE
90FE    CA 9104                     JP      Z,LP3
9101    C3 90FC                     JP      LP2
9104    00                  LP3:    NOP
;
; Read the least significant byte of the A/D conversion
; result and output it to the parallel output board.
9105    DB 02                       IN      A,02H
9107    D3 FD                       OUT     (0FDH),A
;
; Read the most significant byte of the A/D conversion
; result.
9109    DB 01                       IN      A,(01H)
;
; Affix a header of 0000 to identify the ECG as the
; sampled response.
910B    E6 0F                       AND     0FH
;
; Output the most significant four bits of the conversion
; result with a 0000 header to the parallel output board.
910D    D3 FE                       OUT     (0FEH),A
;**********************End ECG sampling.**********************
;
; Clear the A/D converter output ports.
910F    DB 00                       IN      A,(00H)
;
```

```
; Sample the device specified by the value in memory
; location F100H.
9111    3A F100                     LD      A,(0F100H)
9114    D3 03                       AND     8FH
9116    D3 03                       OUT     (03H),A
;
; Delay for 0.00103+ seconds for spacing between sampling
; times.  If the sampling frequency is changed, this delay
; cannot be reduced beyond 0.00004 seconds; if it is, the
; data from the A/D converter will not be valid.
9118    11 0001                     LD      DE,1
911B    21 002D             LPA1:   LD      HL,02DH
911E    ED 52               LPA2:   SBC     Z,LPA3
9120    CA 9126                     JP      Z,LPA3
9126    00                  LPA3:   NOP
;
; Read the least significant byte of the A/D conversion
; result and output it to the parallel output board.
9127    DB 02                       IN      A,(02H)
9129    D3 FD                       OUT     (0FDH),A
;
; Read the most significant byte of the A/D conversion
; result.
912B    DB 01                       IN      A,(01H)
;
; Affix a header which identifies the sampled response to
; the most significant four bits of the conversion result.
```

```
912D    2A F102                         LD      HL,(0F102H)
9130    A6                              AND     (HL)
;
; Output the four most significant bits of the conversion
; result and the identifying header to the parallel output
; board.
9131    D3 FE                           OUT     (0FEH),A
;
; Return to the main program to fetch the number of the
; next channel to be sampled.
9133    C9                              RET
                                        END
```

Appendix F

Strip-Chart Recordings of Analog Physiological Data

This appendix contains strip-chart recordings of the outputs of the physiological monitoring equipment and the Autogen equipment. The measurements were made on a white male adult to provide sample outputs.

All the strip-chart recordings show voltage outputs between -5 and +5 volts with one volt per division vertically. The horizontal time scale for figures F-1 and F-3 was one second per division. For the electrogastogram outputs shown in figure F-2, the time scale was ten seconds per division to allow a full cycle to be displayed.

The significance of each signal shown in figures F-1 and F-2 is explained in chapter 3. The signals shown for the Autogen equipment in figure F-3 are explained in the respective Autogen Manuals.

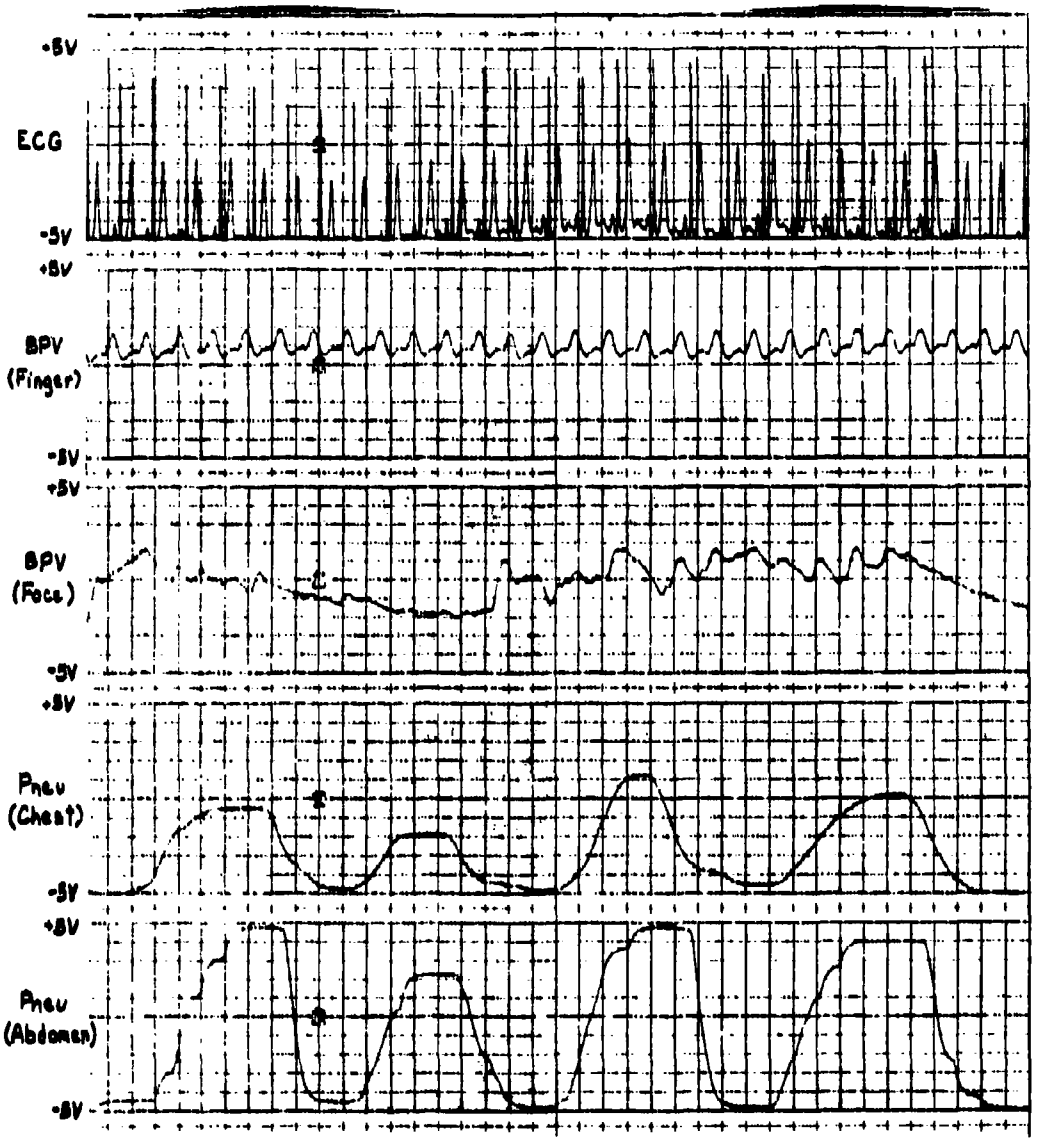


Figure F-1. Biophysical Analog Output Responses

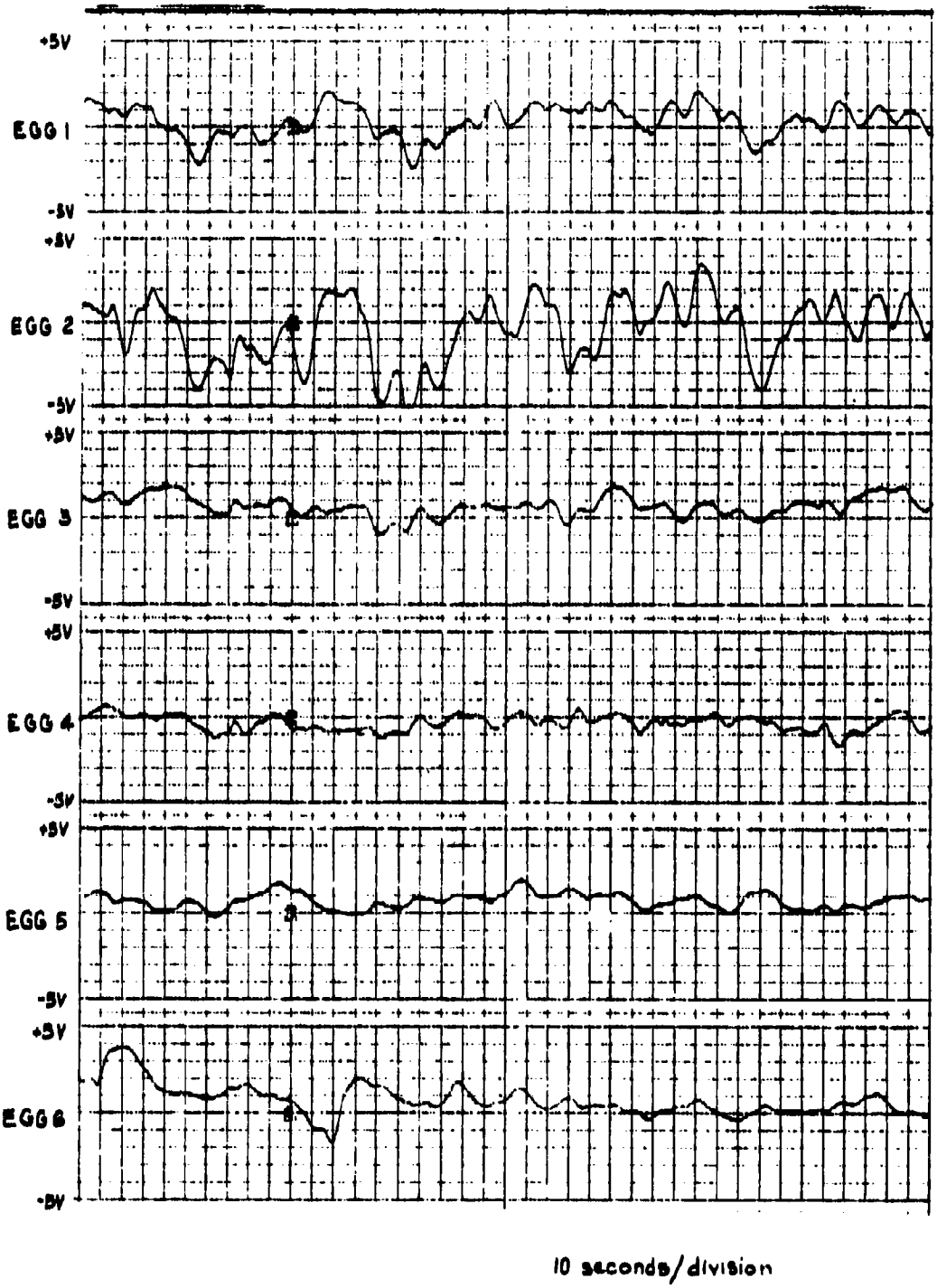


Figure F-2. Electrogastogram Output Responses

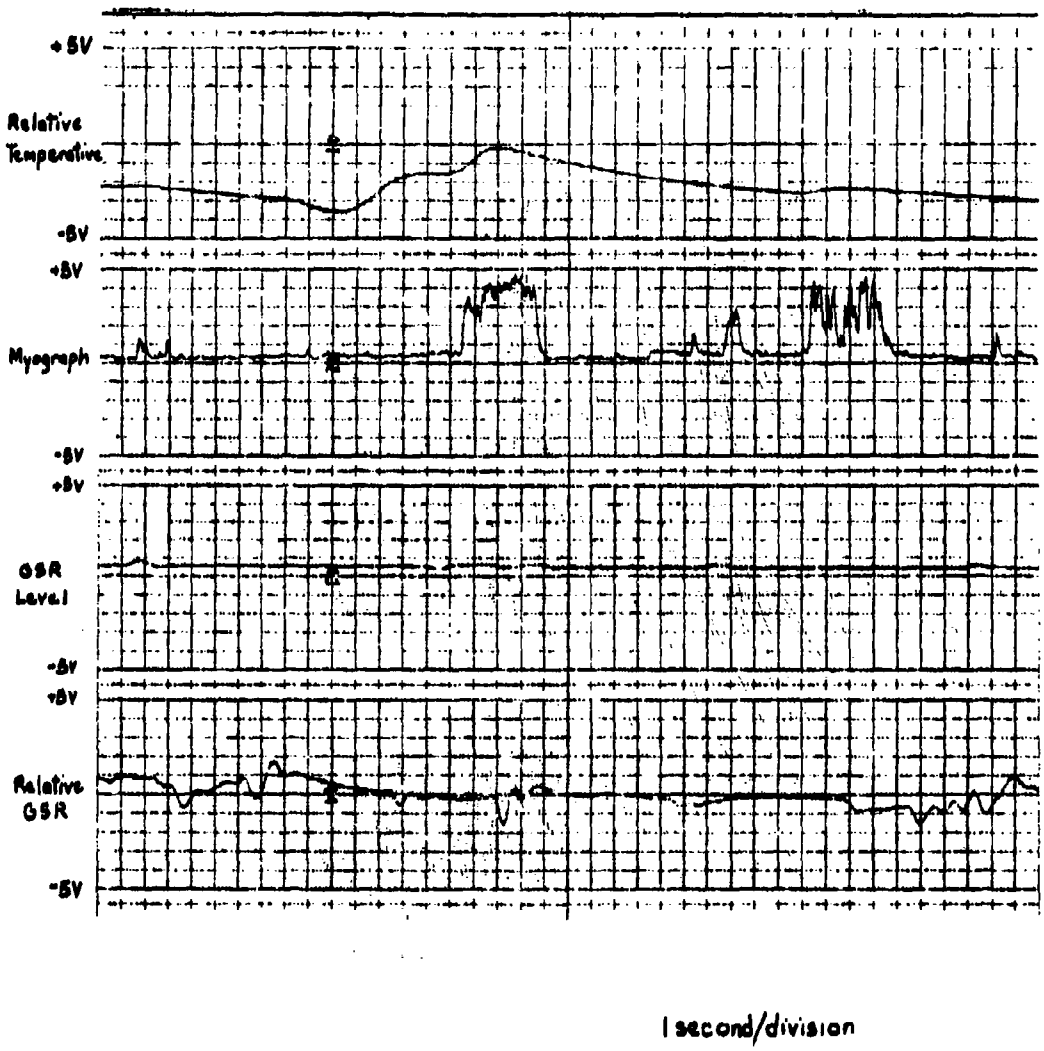


Figure F-3. Autogenic Biofeedback Equipment Outputs

VITA

Orville A. Earl, Jr. was born on August 17, 1955 in Warren, Ohio. He graduated from Bristol High School in Bristolville, Ohio in May, 1973 and enlisted in the United States Air Force in August, 1974. He was selected for the Airman's Education and Commissioning Program in 1976 and in June, 1979 he received a Bachelor of Science Degree in Electrical Engineering from the University of Lowell in Lowell, Massachusetts. Upon graduation he attended the Air Force Officers Training School and in September, 1979 he was commissioned as a second lieutenant.

After commissioning, Lieutenant Earl was assigned to the Electronic Security Command at Ft. George G. Meade, Maryland. There he served as a Integrated Circuit Engineer for the Communications Security Organization of the National Security Agency until April,1982 when he was assigned to the Air Force Institute of Technology, Wright-Patterson AFB,Ohio.

VITA

Charles N. Peterson was born on August 13, 1946 in Richmond, Virginia. He graduated from Henrico County High School in Henrico County, Virginia in June 1965 and subsequently enlisted in the United States Air Force. He was selected for Airman's Education and Commissioning Program in 1976 and in May, 1979 he received a Bachelor of Science Degree in Electrical Engineering from Mississippi State University. Upon graduation he attended the Air Force Officer Training School and in August, 1979 he was commissioned as a second lieutenant.

After commissioning, Lieutenant Peterson was assigned to the Electronic Security Command at Ft. George G. Meade, Maryland. There he served as a Special Collection Systems Engineer for the Operations Organization of the National Security Agency until May, 1982 when he was assigned to the Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

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A physiological data acquisition system and rotating chair were erected to allow future studies on the prevention of motion sickness induced by coriolis stimulation. Physiological monitoring equipment to measure pulse-to-pulse heart rate, gastric motility, respiration rate, and skin pallor were designed and built. This physiological monitoring equipment -

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and commercially available equipment which measures skin surface temperature, galvanic skin reflex (GSR), and electomyogram (EMG) of superficial muscles were integrated into a programmable digital data acquisition system.

The programmable digital data acquisition system provides equivalent digital values for the analog outputs of the monitoring equipment at time intervals which can be chosen by an experimenter. These digital values are transmitted from the chair, through slipsprings, to an output port where signal processing and data recording equipment can be attached.